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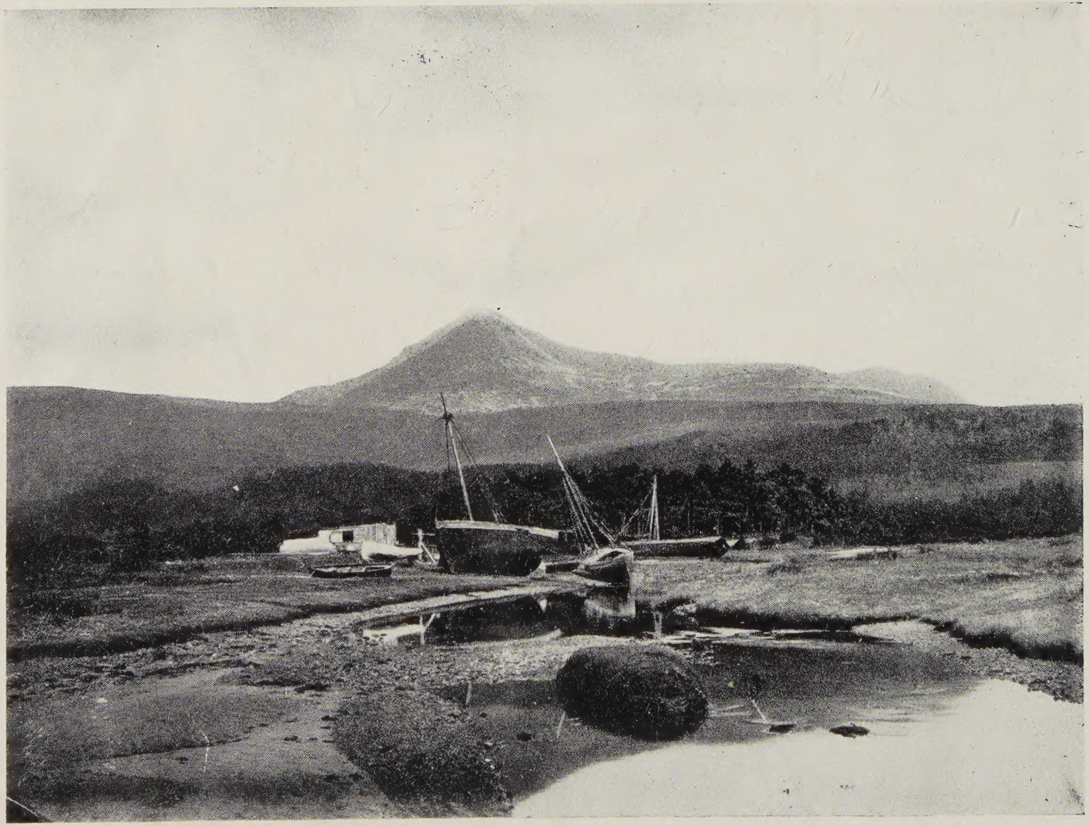

View of ' 1000-Foot Platform ' around Goatfell, from Brodick Bay. [*Frontispiece.*

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Memoirs of the Geological Survey, Scotland

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The
Geology of Arran

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By

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PREFACE

THE six-inch survey of Arran was begun in 1872 by Sir A. Geikie, who mapped a narrow belt along the east coast, and was resumed in 1892 by Mr. W. Gunn, who, under the supervision of Dr. B. N. Peach, completed the detailed examination of the island. To Mr. Gunn's careful and accurate field-work, as embodied in Sheets 21 and 13 (1901 and 1902) of the One-inch Geological Map of Scotland and in the special One-inch Geological Map of Arran, issued in 1910, every student of the geology of this classic area owes a deep debt of gratitude. The geological description of Sheet 21 was published in 1903 ('Geology of North Arran, South Bute, and the Cumbraes, with parts of Ayrshire and Kintyre'), and Mr. Gunn's account of the northern two-thirds of the island, included in this Memoir, is a storehouse of accurate observation and careful deduction. A valuable chapter on the petrography of the Tertiary igneous rocks was contributed to the Memoir by Dr. A. Harker.

The projected Explanation of Sheet 13 was never completed, owing to Mr. Gunn's death in 1902. Since then, geological literature has been enriched by the publication of detailed studies of two other important Tertiary volcanic centres in Scotland—that of Skye in 1904 and that of Mull in 1924. The task of preparing a complete account of Arran geology, presenting Gunn's results and those of later workers in the same area, and including comparisons with the other Tertiary volcanic centres mentioned, was entrusted in 1925 to Dr. G. W. Tyrrell, of the Geological Department, Glasgow University, who has an intimate personal knowledge of the geology of the island. In the preparation of the volume now published, Dr. Tyrrell, in addition to his own published and unpublished work, has drawn freely on the earlier Memoir of 1903 and on the MS. notes on the southern part of the island left by Mr. Gunn. The sources of such contributions are indicated in the text by the initials W. G., W. G. (MS.), and A. H. Dr. Tyrrell also desires to acknowledge the help he has received from the researches of many workers in various fields of Arran geology since 1903, and to express his indebtedness to Dr. G. W. Lee, of the Geological Survey staff, for re-determining and revising the nomenclature of the Carboniferous and other fossils.

JOHN S. FLETT,
Director.

Geological Survey Office,
28 Jermyn Street, London, S.W.1,
31*st October* 1927.

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RENFREWSHIRE COUNTY

THE GEOLOGY OF ARRAN

CHAPTER I

INTRODUCTION AND PHYSICAL FEATURES

The island of Arran is one of the classic regions of geology. It is famous for the great variety and interest of its igneous rocks, and especially for its richness in pitchstones. It has been the field of work of many illustrious geological pioneers—Hutton, Jameson, Playfair, Macculloch, Murchison, Sedgwick, Nicol, Allport, Sorby, and Judd; and among foreign geologists, Ami Boué, Zirkel, Vogelsang, and von Lasaulx. The interest of the island is enhanced by the beauty of its mountain scenery, its archæology, and its instructiveness as a synopsis of the geology of Scotland, with the contrast of the Highland type in the northern part and the Lowland type in the south.

Arran is situated in the Firth of Clyde, lying about 15 miles from Ardrossan on the east, and about 4 miles from the Kintyre peninsula on the west. Its outline is that of an irregular ellipse, the long axis of which, 19 miles in length, extends in a south-south-east direction from the Cock of Arran to Bennan Head, and the short axis, 10 miles in length, from Machrie Bay to Corrygills. The area of Arran is estimated at 165 square miles, and its length of coast-line at 60 miles. Two small islands are attached to Arran: Holy Island, about 2 miles long by half a mile wide, lying across the entrance to Lamlash Bay, and thus making one of the finest harbours in the west of Scotland; and Pladda, about half a mile in length, which lies off the south coast opposite Kildonan.

The most prominent headlands are the Cock of Arran on the north; Clauchlands Point, Kingscross Point, and Dippin Head, on the east; Bennan Head on the south; and Brown Head, Drumadoon Point, and Imachar Point, on the west. The deepest indentations are Brodick Bay and Lamlash Bay, both on the east coast. Loch Ranza is a fiord-like inlet on the north-east coast; and Catacol Bay, Machrie Bay, and Drumadoon Bay are wide but shallow recesses on the west coast.

The most marked physiographic and scenic feature of Arran is the contrast between the rugged granite mountains of the northern half of the island, and the much lower, undulating, plateau and moorland country of the southern part. G.W.T.

The mountains are contained within a nearly circular area about 8 miles by 7 miles across. All the principal streams take their rise in this mass, or from a smaller oval area near the centre of the southern edge of the sheet, which is belted by a granitic ring, and in which are the hills of Ard Bheinn (1676 feet), A' Chruach (1679 feet), and Beinn Bhreac (1649 feet). The streams that flow eastward from this smaller mass of high ground are Benlister Burn and Glencloy Burn, while those which flow to the west are tributaries of the Machrie Water and the Black Water.

The larger granitic area is divided into two nearly equal parts by the glens of Iorsa Water and Easan Biorach, which coalesce at the watershed of Loch na Davie. The Iorsa stream, which is about 8 miles long, is the largest in the island. Some of its branches drain the western part of the high ground, which is not so high and rugged as the eastern half, nearly all the highest hills being round or flat topped. Beinn Bharrain (2345 feet) and Beinn Bhreac (2333 feet)—the highest points of a continuous ridge ; Meall nan Damh (1870 feet) and Meall Mòr (1602 feet), isolated conical hills ; and another Beinn Bhreac (1881 feet), west of Loch na Davie, are the most important summits in this part, which is partly drained by Allt Gobhlach and the stream which flows north down Glen Catacol.

From the masses of Caisteal Abhail (2817 feet) and Cir Mhòr (2618 feet) diverge ridges that embrace the glens of Sannox and North Sannox, which drain eastwards, and that of Rosa,[1] which drains southward into Brodick Bay. One ridge with a gradual descent runs northwards from Caisteal Abhail to Creag Dubh, and bounds the valley of North Sannox on the west. Another, and very rugged, ridge runs eastward to the rift of Ceum na Caillich, and then in a smooth outline continues in a north-east direction past Suidhe Fhearghas (2156 feet). This ridge separates the two Sannox glens. A high col, the lowest part of which is 2046 feet, joins Caisteal Abhail to Cir Mhòr. In a south-south-west direction from this peaky mountain we have successively A' Chir (the most difficult to traverse in the whole island), Beinn Tarsuinn (2706 feet), and Beinn Nuis (2597 feet). The height of A' Chir is not given, but is probably about 2335 feet, and the pass to the south of it is over 2000 feet, while the pass on the north side is 1933 feet. The highest point of Beinn a' Chliabhain, which is on the west side of Glen Rosa, is 2217 feet in height. Cir Mhòr is connected with the Goatfell range by the low col of The Saddle (1414 feet), which has a precipitous and difficult descent on the Sannox side. Goatfell (2866 feet), the highest summit in the island, is on a continuous range of high ground, over 2000 feet in elevation, which runs in a curved line from Cioch na h-Oighe (2168 feet), round the head of the White Water, past Goatfell, some half a mile down its southern spur. For three-quarters of this distance the ridge is nearly everywhere over 2500 feet, and only falls slightly below that height at one or two points. From its highest point north of Goatfell (2716 feet), a ridge which bounds the White Water on the north runs eastward to Am Binnein (2172 feet). W.G.

The southern part of the island has not the striking scenery of the north. It is mostly an undulating tableland, the highest part of which rises to 1500 feet above sea-level. The watershed between the streams flowing east and west runs in a north-westerly direction from Dippin to the head of the Monamore Glen, and for the greater part of its course it is above the 800-foot contour. Being much nearer the east than the west coast, it follows that the longer and more important streams are on the west side. Those on the east have a rapid fall, and their courses are generally diversified by waterfalls. Very little of the ground is below 100 feet in elevation. The principal exceptions are the valley of the Black Water, and the coastal strip about Sliddery.

---

[1] Glen Rosie on One-inch Geological Map (1910).

The highest point is about 1500 feet above the sea, some 40 yards to the north-east of the ordnance station on Tighvein, which is 1497 feet. Cnoc Dubh, to the north-west of Tighvein, is 1385 feet high. Sguiler (1332 feet), and The Ross, Monamore Glen (over 1000 feet), are the most conspicuous hills behind Lamlash. The ordnance station on The Ross is 989 feet ; and many of the stations marked in the southern half of the map are on gently rising hilltops which are not conspicuous from a distance. The highest hill in the central area is Cnoc a' Chapuill (1369 feet) ; Cnoc na Dail, a prominent hill to the south of this, is 1158 feet. To the west are Tormusk (1259 feet) and Cnoc an Loch (1107 feet). Cnoc Ballygown (735 feet) is a steep hill overhanging the valley of the Black Water ; and east of Brown Head there is a somewhat isolated mass of high ground, the highest point of which is Cnoc Reamhar (737 feet). Several of the hills in the south-eastern part of the island, as Levencorroch and Auchenhew Hills (909 feet), are flat-topped and covered with peat, though they often have good scars and marked topographic features round their borders. Cnoc na Garbad (959 feet), Cnoc na Comhairle (913 feet), and Borrach (869 feet) are prominent hills in the region behind Whiting Bay.

The coast is for the most part bold and rocky, with fine cliffs at Dippin, Bennan, and Drumadoon. The island of Pladda, though rocky, reaches a height of but 70 feet, and forms a great contrast to Holy Island, which rises abruptly from the sea to a height of 1030 feet in a series of crags, making a feature almost as striking as Ailsa Craig. The eastern side is the steeper, the horizontal distance from the sea-level to the ordnance station on the summit being only 1100 feet, so that the average slope is nearly 1 in 1, or about 45°. W.G. (MS.)

The streams of the northern mountain area comprise both a minor radial system and a major 'through' system of drainage. The radial streams with their trends are listed by Prof. J. W. Gregory [1] as follows :—

N.E.	Two streams of North Glen Sannox.
E.N.E.	Glen Sannox.
E.	Four streams near Corrie, of which the longest is the White Water Burn.
S.E.	Merkland Burn and Cnocan Burn, coming from Goatfell.
S.	The eastern Garbh Allt from Beinn Nuis ; and Auchencar Burn from S.S.W. of Beinn Tarsuinn.
S.W.	Glen Scaftigill.
W.	Eight burns, of which the longest is the Allt Gobhlach.
N.W.	Abhainn Bheag.

The above are all of secondary importance. The greater streams run in three major valleys which cut across the granite range from north to south. In the longest of these valleys are the Iorsa and the Easan Biorach, running respectively south and north from a col at 1182 feet above sea-level in the very heart of the mountains. The Rosa Water occurs farther east, and over the pass of The Saddle its valley is continued by Glen Sannox, bending round gradually to the north-east. The third main valley is that of Glen Catacol and Glen Scaftigill, on the western side of the mountains. In the extreme north-east is another major valley consisting of Glen Chalmadale and North Glen Sannox. These valleys contain the most considerable streams in Arran, the largest being the Iorsa, with a length of about 8 miles.

---

[1] 'The Pre-Glacial Valleys of Arran and Snowdon,' *Geol. Mag.*, vol. lvii., 1920, p. 150.

The principal streams in the central part of the island are Glen Shurig, Glen Cloy, with its two headwaters, Glen Ormidale and Glen Dubh, the Lag a' Bheith (Birch Glen), and Benlister Glen, on the east. The first three debouch into Brodick Bay ; the last into Lamlash Bay. On the western side of the watershed there is first the Machrie Water, with its tributaries, Gleann Easbuig (Bishop's Glen), the western Garbh Allt, and Glen Craigag draining the ' central vent ' area ; and the Black Water entering Drumadoon Bay, with its main tributary the Ballymichael Burn and its headwater the Clauchan Burn.

In the southern third of the island the Sliddery Water is the longest stream and drains the largest area. Its principal sources rise near Cnoc a' Chapuill and Cnoc Dubh. The Kilmory Water has its sources in the high ground of Tighvein. It has an important tributary on the north side called the Cloined Burn (Allt Mòr Cloined). Some small streams run southward, and have short courses and a rapid fall. The most important of these is Allt Mòr, which rises in Loch Garbad. A fine waterfall occurs in this stream east of Auchenhew Hill. On the east side of the island the Monamore Burn and the Kingscross Burn both rise in Urie Loch. The former of these streams runs at first in a north-north-east direction and then turns eastward to flow into Lamlash Bay ; while the latter takes an easterly course and runs into Whiting Bay. The largest burn on the eastern side is that which rises to the south-east of Urie Loch, and flows south-east, and then east into Whiting Bay. This burn, which is called the Allt Dhepin in its upper part, has a fine series of waterfalls ; and in its lower course, where it is called the Glen Ashdale Burn, it possesses the highest fall in Arran. This fall is in two leaps—a higher one of about 40 feet, and a lower of 100 feet. In its setting of pine wood this is the most beautiful scenic feature of southern Arran. G.W.T.

Several freshwater lochs diversify the surface of Arran, nearly all of which are in the western part of the island. The largest is Loch Tanna, which is a mile in length, but not particularly interesting, being immediately surrounded by low-lying, peat-covered ground. It is probably shallow, and drift-dammed. The Dubh Loch to the west of it is partly surrounded by rock, and may be a rock basin. Loch Nuis and Loch Iorsa are shallow lochs, probably in drift, as is also Loch na Davie. Two small lochs occur to the south-west of Sail Chalmadale, one of which is not on the ordnance maps. The finest of the lochs is Loch Chorein Lochain at a height of 1080 feet above the sea, picturesquely surrounded by granite crags between Meall nan Damh and Meall Biorach. W.G.

Four small freshwater lochs are found in the southern half of the island. Loch Cnoc an Loch, the largest, is 1004 feet above sea-level on the high ground east of the Black Water. From it rises a tributary of the Clauchan Burn. Urie Loch, the source of the Monamore Burn, has a dam at its outlet, and when the loch is high it overflows at its head, and becomes also the source of the Kingscross Burn. This loch is a quarter of a mile in length, and is 1329 feet above sea-level. A mile to the south-east of this lies Loch na Leirg, 250 yards long and 1024 feet above sea-level. Loch Garbad, 350 yards long, and at a height of 759 feet, is the source of the Allt Mòr, which enters the sea east of Auchenhew. This loch is surrounded by crags, and appears to be a moderately deep rock basin. W.G. (MS.)

Around the coasts of Arran is a narrow strip of low ground, usually less than a quarter of a mile wide, consisting of the various raised beaches and rock terraces which fringe the island. This feature expands to a width of a mile or more in a few places, as in Brodick Bay and Lamlash Bay on the east coast ; Sliddery on the south ; Drumadoon Bay, with the valley of the Black Water, and Machrie Bay on the west ; and Catacol Bay and Loch Ranza in the north. The ground rises abruptly from the inner margins of this feature. Occasionally the coast is bold and rocky, and forms fine cliffs, as at Dippin, Bennan, and Drumadoon. There are important remnants of high-level plateaus in the interior of the island, notably the '1000-foot' platform surrounding the northern mountains (Frontispiece) ; but these are more fully dealt with in a later chapter (p. 256). G.W.T.

CHAPTER II

SUMMARY OF GEOLOGY; HISTORY OF INVESTIGATION

The following table gives a complete list of the various formations, exclusive of Pleistocene and Recent deposits, which are to be found within the island of Arran. They are arranged in order from the youngest to the oldest. The igneous rocks, both intrusive and extrusive, are included in the formations of the geological period, within which their eruption is believed to have fallen. The symbols by which the various formations are indicated upon the colour-printed geological map of Arran are also appended.

Kainozoic—			
Basalt and olivine-dolerite dykes of tholeiitic and crinanitic composition			B
Pitchstone dykes and sills			F′
Quartz-porphyry and quartz-felsite			F
Quartz-porphyry—hypersthene-dolerite composite sills (Bennan, Drumadoon, etc.)			F″
Augite-diorite and granite of Tighvein			B+G′
Ring structures of central area		Granite, granophyre, and felsite intrusions	G, G′, G″
		Gabbro and diorite intrusions	U+D
		Rhyolitic agglomerate, with included masses of felsite and rhyolite	Ni
		Basaltic agglomerate, with blocks and masses of Kainozoic basalt lavas	Ni
		Breccia and conglomerate, chiefly of Old Red Sandstone material	Ni
Granite of northern boss			G
Dolerite-granophyre and basalt-felsite composite sills and dykes			B
Dolerite, quartz-dolerite, and craignurite sills and dykes			B
Crinanite sills and large early crinanite and olivine-dolerite dykes (Dippin, Kingscross, Monamore Glen, Clauchland Hills, etc.)			B
Mesozoic—			
Cretaceous		Limestone with siliceous concretions, occurring in volcanic vent	h
Lias		Dark shale with many fossils, occurring in volcanic vent	g
Rhætic		Black shale with ironstone and limestone, occurring in volcanic vent	fg
		Pale-coloured mudstones, do.	
New Red Sandstone		Upper Division (Trias)	f′
		Lower Division (Permian)	f
Palæozoic (Upper)—			
Carboniferous		Coal Measures with contemporaneous lava	d^5
	Carboniferous Limestone Series	Upper Limestone group	d^2
		Edge-coal group	
		Lower Limestone group	
		Calciferous Sandstones with intercalated volcanic series, and intrusive rocks	d^1
Old Red Sandstone		Upper Red Sandstones and conglomerates with volcanic series	c^3
		Lower Red Sandstones, mudstones, and conglomerates with volcanic series, and intrusive rocks	c^1

PALÆOZOIC (LOWER)—		
Ordovician (?)	Cherts, grits, and dark schists associated with a greenstone, spilite, epidiorite series ..	b
PRE-PALÆOZOIC—		
Dalradian ..	Mica-schist	𝔤
	Limestone	λ
	Slate	𝔩
	Gritty schists or schistose grits	𝔷

SUMMARY OF THE GEOLOGY

The oldest rocks in Arran are the mica-schists, phyllites, slates, and schistose grits, which are believed to belong to the Dalradian Series. These rocks form an incomplete ring round the granite in the northern parts of Arran where they occupy high ground generally; for though the formation is found on the seacoast from Dougrie to Newton the land rises rapidly from the sea-level. The outcrop is interrupted from near Glen Sannox to the White Water on the eastern side of the granite, a distance of about 3 miles. The schists often occupy a kind of plateau rising to over 1000 feet in the district reaching from Glenshant Hill to Whitefarland (the '1000-foot' platform). In the north-east of Arran the formation attains a height of 1453 feet above the sea. Crags and minor features are common in the formation, both on the coast and inland, some of which are in a great measure due to joints or faults.

Next in order of age are the presumably Arenig rocks which occupy a restricted outcrop in North Glen Sannox. These consist mainly of spilitic lavas, now in the condition of greenstone or epidiorite, with subordinate slates and schistose grits. The outcrop is bounded on both sides by gritty schists which are assigned to the Dalradian.

Separated from the metamorphic rocks by a fault, the Lower Old Red Sandstone of the northern half of Arran occupies in the main a curved strip, marked by steep dips, stretching from Corloch on the east side of Arran to Dougrie on the west coast. The conglomerates of this division form prominent hills in North and South Glen Sannox, but the highest point of this band is An Tunna (1184 feet), north of the String Road. There is also a detached portion of this sub-formation to the east and south of the smaller granite area at the heads of Glen (Gleann) Dubh, Benlister Glen, and Clauchan Glen. It rises to 1346 feet in Cnoc na Croise.

The greater part of the Central Ring area must be underlain by Lower Old Red Sandstone, since blocks and masses of the conglomerates and sandstones of this formation make up a very large proportion of the breccias here produced by Kainozoic volcanic action.

Rocks assigned to the Upper Old Red Sandstone occupy the shore between the Fallen Rocks (near Corloch) and Corrie, and they form a narrow band to the east and south of the Lower Old Red Sandstone and apparently conformable to that division. On the north side of North Glen Sannox the conglomerates of this division form a marked set of features with a northerly dip, and here they may be unconformable to the lower division. They also occur in a narrow semicircular strip to the south of the Central Ring area, about the heads of the Benlister and Clauchan Glens.

Volcanic rocks of Lower Old Red age are found only on the west side of Arran in a narrow inconspicuous band, and those of Upper Old Red age occupy a much-faulted strip on the east side of the island between the mouth of North Glen Sannox Burn and Corloch.

A conspicuous intrusion of salite-diabase occurring in the Lower Old Red Sandstone on the south side of Glen Rosa may doubtfully be referred to igneous activity of Lower Old Red Sandstone age.

Both Lower and Upper Carboniferous rocks occur in North Arran, from the Cock to the Fallen Rocks, where they occupy a narrow band dipping steeply northward, and bounded on the west by a fault. To the east and south-east of the northern granite there are to be found five areas of Carboniferous rocks, the outcrops of which are arranged in echelon roughly following the boundary of the granite, and are caused by its circumferential and radial faulting. Several other narrow strips of Carboniferous rocks are found on the south-east and south of the Central Ring area, where they are bounded by faults radial to the ring.

Basalt lavas and tuffs of Lower Carboniferous age occur in several of these areas, notably near Corrie, and in the outcrops at the head of Benlister Glen. At the head of the southern branch of the Sliddery Water is an area of Carboniferous rocks consisting chiefly of tuffs and lavas, but containing also shales and sandstones with fossils which show that the whole series is mainly of the age of the Lower Coal Measures.

Disregarding for the moment the extraordinarily abundant Kainozoic igneous rocks, it may be said that the remaining parts of Arran are underlain by formations belonging to the New Red Sandstone. In the Memoir on Sheet 21,[1] and on the geological maps, these rocks are assigned entirely to the Triassic ; but Prof. J. W. Gregory has recently recognized four divisions (*see* p. 76), the two lowermost of which are referred to the Permian, and the two uppermost to the Triassic. The Corrie freestone, a round-grained red sandstone of æolian origin, occupies an area of little more than half a square mile at the Cock of Arran ; but its main outcrop is in the coastal strip between Corrie Hotel and Brodick Bay. The succeeding, or partly contemporaneous, Brodick Breccia also appears to be a desert accumulation, as some of the pebbles are wind-facetted. It occurs mainly on the south side of Brodick Bay, and in the region of the Glen Cloy Water and its tributaries. Fine cliff sections (Creag nam Fitheach) occur on the south side of Glen Dubh. About Lamlash and Whiting Bay occur coarse red and white sandstones with occasional conglomerates, which are doubtfully assigned to the Upper Permian.

The upper series consists of various sandstones, often calcareous and micaceous, with red shales, earthy limestones, and marls which are indistinguishable from typical English Keuper marls. This series is clearly of aqueous origin, and was probably laid down under lagoon conditions. It occupies most of the south and south-west of Arran, and good sections are to be seen at Auchenhew, Levencorroch, and Sliddery.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 67.

A band of volcanic conglomerate and breccia, chiefly of basaltic composition, has been found within the Brodick Breccia in the Glen Dubh Water. This may represent a volcanic episode of Permian times, or may be due to the erosion of an area of Carboniferous basalts.

The Triassic, Rhætic, Lias, and Cretaceous formations are represented by fragments and masses which have been preserved by their incorporation within the Central Ring structure of Arran.

In Kainozoic times Arran became one of the principal igneous centres in the west of Scotland. The basaltic lavas which were doubtless produced here, parallel with those of Skye, Mull, and Antrim, have long been swept away by erosion, with the exception of one or two remnants preserved within the Central Ring. The main feature of Kainozoic igneous activity in Arran is the production of ring structures similar to those of Mull and Skye. The finest of these occurs in the very centre of Arran, about the hills of Ard Bheinn, A' Chruach, and Beinn Bhreac, to the south of the String Road. The map shows the interrupted annular disposition of the various component rocks, and more recent mapping has confirmed the ring shape (Plate IV). Three kinds of conglomerate and agglomerate are represented within the ring, which, arranged in order of abundance, are : broken masses of sedimentary rocks, chiefly Old Red Sandstone, rhyolitic agglomerate, and basaltic agglomerate. Early intrusions of gabbro and diorite take part in the structure, but the greater part of the area is taken up by a massive intrusion of granite or granophyre. The explosive activity of this centre seems to have been due to the intrusion of acid magmas, just as in the similar ring structures of Mull and Skye.

The greatest mass of Kainozoic igneous rock, however, is the northern granite boss, the erosion of which has produced the striking mountains of northern Arran. This granite has a roughly circular outcrop with a diameter of about 7 miles. It may be interpreted as a very deep-seated section of a ring structure, the upper fragmental parts of which have been eroded away. The intrusion of this granite was attended by interesting tectonic phenomena in the surrounding rocks.

Arran is riddled with innumerable minor intrusions, plugs, sills, and dykes in great profusion, which cause all the greater elevations and most marked features in the southern half of the island. The intrusions consist of both basic and acid members, of which the former are in general the earlier, although the igneous episode seems to have been closed by the intrusion of multitudes of basalt dykes, forming a swarm running north-west to south-east or north-north-west to south-south-east, roughly parallel to the Mull Swarm. The great crinanite (olivine-analcite-dolerite) sills of Dippin, Kingscross, Monamore, and Clauchland, in the south-east quadrant of the island, seem to be among the earliest intrusions of the Kainozoic igneous episode in Arran. Composite sills, consisting of dolerite and granophyre, or basalt and felsite, occur abundantly, and are associated with the intermediate rocks called craignurite in Mull. The acid rocks include quartz-porphyries (Bennan, Drumadoon, Dun Dubh, etc.), some of which are associated in composite sills with hypersthene-basalt, felsites, and the pitchstones for which Arran is famous. Holy Island has recently been found to consist of an extremely uniform mass, 800 feet thick, of riebeckite-orthophyre or trachyte.

The present topographic features of Arran were all developed after the cessation of Kainozoic volcanic activity. The most important event of this period was the cutting of the 1000-foot rock platform (1000 to 1200 feet) over the island, the remains of which are especially well preserved around the northern granite mass (Frontispiece). The date of this feature is believed to be Pliocene. During the Glacial Period the Arran mountains nourished a local ice centre, from which ice streams pressed to the south, distributing numerous large granite erratics over the southern half of the island, but barely holding their own on the east and west against the great ice streams filling the Firth of Clyde and Kilbrannan Sound.

Since the Glacial Period an intermittent uplift has produced a series of raised beaches fringing the coasts. These occur roughly at 10 feet, 25 feet, and 100 feet above sea-level, with a variable series of beaches at intermediate levels. W.G., G.W.T.

History of Investigation

The history of investigation of Arran geology opens with a few references to geological matters in Thomas Pennant's *Tour to the Hebrides* (1774). Only a general description of the island is given in this work, but the reference to the Drumadoon quartz-porphyry sill as 'a long range of columnar rocks (not basaltic) of hard grey whinstone, resting on an horizontal stratum of red stone; at the extremity one of the columns is insulated, forming a fine obelisk' (vol. i. p. 182), betokens acute observation of geological features. Pennant also noticed the occurrence of pitchstone at Dun Fionn (p. 185), and the former working of coal at the Cock of Arran.

But the most memorable early references to the geology of Arran are contained in the *Theory of the Earth* (1795), by the immortal James Hutton, the Father, as we may call him, of Igneous Geology. The third volume of the *Theory of the Earth*, not published till 1899 under the editorship of Sir A. Geikie, contains the first complete account of Arran geology that was ever written, if not published. One is only able to marvel at the astounding modernity of this description, which was probably written prior to 1795. As Sir A. Geikie says: 'This striking essay is a masterpiece of acute observation and luminous generalisation.' In it Arran is divided into five main geological regions: the northern granite; its investment of *schistus*; the secondary and tertiary strata comprising much of the rest of the island; the porphyries, and the whinstones, which break through these formations. The descriptions of these divisions are full of original observations and inferences. Modern petrography is represented by a reference to the quartz-felspar-porphyry of Brown Head: 'this ground [groundmass] is maculated with the crystalline or transparent quartz and the felt-spath. I would therefore term it a granite-porphyry, as containing almost the same materials as granite, only in a porphyry form' (p. 212). The general ground of the porphyries is *petuntze* or porcelaine-stone, and is an intimate mixture of the felt-spath and siliceous substance (p. 213). What appears to be a reference to xenocrystic minerals in basalts and dolerites occurs in the following passage: 'The whinstone in this island is sometimes maculated with felt-spath, and that peculiar quartz which is characteristic of the Arran granite' (p. 216).

Hutton clearly distinguished sills from transgressive intrusions, and descants on the extraordinary number of dykes in Arran, mentioning particularly the long dyke of Glen Rosa. He noticed that the dykes occasionally intersected the horizontal beds (*i.e.* sills) of whinstone, and therefore represented the latest phase of eruption. Sir A. Geikie comments on the modernity of this observation. In describing the pitchstones Hutton noted the crystallites they contain, and observed the close relation between pitchstone and felsite. The germ of the idea of composite dykes is contained in his allusions to the Tormore pitchstones, and their association with *petuntze* or felsite and whinstone (p. 254). He described the Kildonan Castle sill as a 'bed of whinstone . . . of a peculiar nature, much approaching to petuntze' (p. 259), which is a perfect description of the intermediate characters of the craignuritic type of which this sill is composed.

With regard to structural geology Hutton's genius was fully exhibited in his recognition of the Lochranza unconformity (*Theory of the Earth*, vol. i., 1795, p. 429). The passage is worth quoting: 'Here the schistus and the sandstone strata both rise inclined at an angle of about 45°; but these primary and secondary strata were inclined in almost opposite directions; and thus they met together like the two sides of a *lambda*, or the rigging of a house, being a little in disorder at the angle of their junction. From this situation of those two different masses of strata, it is evidently impossible that either of them could be formed originally in that position; therefore, I could not here learn in what state the schistus strata had been in when those of the sandstone, etc., had been superinduced.' In vol. iii. (pp. 235–6) the further observations are made that the secondary strata are a 'composition of sandstone and limestone [cornstone],' and that they 'overlap the ends of the alpine schistus,' and are therefore the superincumbent body. Hutton also noticed the increasing dip of the strata as they approach the schistus in Glen Rosa (p. 218), and stated that the apparent stratification of the Goatfell granite was 'occasioned by the regular contraction or basaltic cracking of the mass in cooling' (p. 228).

R. Jameson, in his *Mineralogy of the Scottish Isles* (1800), gives a geological description of Arran which was published separately two years earlier. His account, which, of course, is thoroughly Wernerian in its point of view, is circumstantial, but contains hardly anything new, either as to facts or ideas. He gives a full description of the composite dykes of Tormore, accompanied by a very good plan of the shore (pp. 102–5).

In his *Illustrations of the Huttonian Theory* (1802), Playfair, the interpreter of Hutton, merely reinforces the arguments of his master in regard to the lessons of Arran geology.

The next investigator, the Rev. J. Headrick, in his *View of the Mineralogy, Agriculture, Manufactures, and Fisheries of the Island of Arran* (1807), while always Wernerian, and occasionally venting gentle sarcasm on the Plutonist ideas of Hutton and others, nevertheless contributed a large body of original information on the geology of Arran. He noticed that the inclinations of the granite slabs on Goatfell approximated to that of the slope on which they occurred. On p. 273 he says : ‘The further the schistus was removed from the granite, the more its strata were inclined towards it ; but near the junction, they were absolutely perpendicular, or, by strange contortions, bent backwards, as if afraid to face the granite,’ which seems to be a foreshadowing of modern tectonic views.

In 1819 John Macculloch published a full account of Arran and its geology in his well-known *Description of the Western Isles of Scotland* (vol. ii. pp. 311–439). He realized that the stratification of the granite was only apparent, and guardedly asserted that the granite passed laterally into the surrounding schists (pp. 345–6), basing that opinion on a confusion between the pseudo-stratification of the granite and the foliation of the schists. He also pointed out the petrological similarities between the granites of Arran, Skye, and St. Kilda. Macculloch seems to have been the first to subdivide the schists into ‘micaceous schist, which forms the adjoining districts of Cantyre and Cowal [and] . . . the argillaceous schist which follows that rock in the order of superposition’ (p. 359), and to connect the Arran schists with those of the adjacent districts in the Clyde region. In one passage Macculloch employed a method used by later geologists to determine the relative ages of the schistose rocks when he pointed out that one of the varieties of chlorite-schist in Glen Chalmadale contained ‘distinct imbedded fragments of common blue clay slate’ (p. 363). Comparing the regular disposition of the schists in Bute and in adjacent parts of the mainland with their confused arrangement in Arran, he implied that the granite was the cause of the irregularities in Arran (p. 365).

In describing the Secondary strata of Arran, Macculloch wrote clearly of the Old Red Sandstone, the Carboniferous, and the New Red Sandstone, although not under those names. He noticed that where these strata approach the granite, ‘they are in a certain degree adapted to its general outline ; being elevated at angles, often of considerable inclination, and incurvated to suit the forms of that rock, or those of the primary strata which are interposed’ (p. 385). He goes on to point out that : ‘If the . . . phenomena of the junction of the granite and schist are allowed to prove the elevation of the latter, it may follow that the same cause has elevated the Secondary strata, and that the granite is posterior to them, as it is to the schist ' (p. 386), which appears to be the first statement of the post-Secondary age of the Arran granite. In further support of this view he adduces the fact that no Arran granite fragments occur in the neighbouring conglomerates (p. 388). Macculloch's account of the Kainozoic igneous rocks of Arran, while very full, does not present any great novelty. He gives a good description of the Drumadoon quartz-porphyry sill, with its lower layer of non-porphyritic [basaltic] rock.

In the following year, 1820, appeared Ami Boué's famous *Essai géologique sur l'Ecosse,* which contains a number of interesting references to the geology of Arran. Perhaps the most interesting is his description of Holy Island, the rock of which he calls a phonolite, and compares with those types from the Auvergne region with which he was so familiar.

Modern modes of investigation of the Secondary rocks of Arran began with the paper by Sedgwick and Murchison in 1828 (published 1835), in which the younger series of red rocks in the island were correctly referred to the New Red Sandstone. In 1829 a notable German work on the geology of Arran was published by K. von Oeynhausen and H. von Dechen. John Paterson's *Prize Essay in the Transactions of the Highland and Agricultural Society of Scotland* (1837) is chiefly valuable for its copious references to agricultural matters in Arran.

In 1840 the Royal Society of Edinburgh published L. A. Necker de Saussure's remarkable memoir on the dykes of a part of Arran, the first detailed treatment of the Arran Swarm. Necker estimated that there were at least 1500 exposed and unexposed dykes in Arran. He gives an elaborate tabular statement of 149 dykes exposed in the northern and east central parts of the island, classifying his observations under the headings of locality, nature, state (weathering, etc.), direction, thickness, hade, rocks traversed, and remarks. Further reference is made to his results in Chapter XV., in which the Arran Dyke Swarm is more fully discussed. Necker also first described and named a new granite area (the so-called Ploverfield granite) in the Central Ring Complex bordering the String Road, which had, however, been observed by Ramsay in 1837.

In the same year (Sir) A. C. Ramsay published his geological map of the island, which was followed in 1841 by his memoir, *The Geology of the Island of Arran from Original Survey.* This was the first complete geological map, and the first published memoir devoted entirely to the geology of the island. The memoir is packed with new facts and descriptions, but is not prolific in new ideas or interpretations. Ramsay was apparently the first to put forward the notion that the apparent stratification of the granite was due to cooling propagated from the overlying schists, and conformed to their structures : and he also thought that the granite had been thrust up bodily in solid form. Both these ideas were later developed in detail by John Smith. Ramsay also gives a very good description of the mylonite band between the granite and the Old Red Sandstone in the White Water, although he had no idea of its true nature, and believed it to be an attenuated representative of the encircling schists. At this date, moreover, Ramsay had not grasped the intrusive character of the trap and porphyry sills, since he always spoke of them as having 'overflowed' the strata.

James Bryce was the investigator of Arran next in succession to Ramsay, if we exclude the Rev. David Landsborough, who, in 1847 and 1852, published a popular account of some excursions in the island and a poem. In 1855 Bryce published some geological notes on Arran, which may be regarded as the first edition of his book, and announced the discovery of a new granite area at Craigdhu or Derenenach. His book, *The Geology of Clydesdale and Arran*, published in 1859, with further editions in 1865 and 1872, long remained the standard work on the geology of the island. Of it may be said, as of Ramsay's work, that it added numerous new facts and observations, but little of new ideas or interpretations. In one respect, indeed, it regressed, as Bryce always refused to regard the predominant red sandstones of Arran as anything but Carboniferous, and poured scorn on the idea of their New Red Sandstone age. Bryce noticed the 'abrupt changes of dip' in the schists north of Glen Catacol, but speaks of the structure as an anticlinal, although the most prominent structural feature on that shore is a decided syncline. He was the first geologist definitely to recognize and describe the traces of glaciation in Arran. He noted many striæ, roches moutonnées, and erratics, and pointed out the morainic characters of accumulations in Glen Iorsa, Glen Catacol, and Glen Rosa.

In 1864 the Rev. R. Boog Watson published a full account of shell-beds which he had discovered in the boulder-clay of the south of Arran. In the following year Bryce pointed out that the shells occurred at a definite horizon between stiff boulder-clay due to land ice, and more sandy drifts which he ascribed to the reworking of the boulder-clay by local glaciers and rivers after a marine submergence that had given rise to the shell-bed.

Meantime, in 1858, H. Sorby had published his epoch-making paper on the microscopic structures of crystals, including therein an account of the Arran pitchstones, which therefore figured in the very dawn of microscopic petrography. In 1863 and 1867 F. Zirkel described the microscopic features of the Arran pitchstones in well-known early works. He was followed in 1872 by S. Allport, who contributed two papers on the pitchstones to the *Geological Magazine*. Two years later, in his famous paper on the microscopic structure and composition of the British Carboniferous dolerites, Allport described the Clauchland sill as a dolerite with 'a clear amorphous glass in the interstices of the constituents,' a material which has since been identified as the mineral analcite. He also described the dolerites of The Ross, and the Dippin sill, as well as the 'traps' of Kildonan Castle, Auchenhew, and Levencorroch.

In 1866 E. A. Wünsch discovered stumps of fossil trees embedded in 'trappean ash' at Laggan Bay, which belong to the Calciferous Sandstone Series. In 1874 Wünsch and Thomson made the momentous find of derived Carboniferous fossils in the breccias near the Cock of Arran, a discovery which established, once for all, the New Red Sandstone age of the breccias, red sandstones, and associated marls, which occupy the greater part of Arran.

In the seventies of the nineteenth century the visits of foreign geologists to Arran were renewed, and important memoirs were published by F. Zirkel (1871) and A. von Lasaulx (1878). Prof. von Lasaulx (*see* Wünsch's summary of his views in *Trans. Geol. Soc. Glasgow,* vol. vi., part ii., 1882, pp. 165–181) regarded the granite as having been intruded prior to the 'Silurian' slates, and as having been forced up with them by great lateral mountain-making movements. In this he was doubtless misled by the erroneous views of the older writers, especially Bryce, as to the age of the granite and of the New Red Sandstone. Wünsch himself, however, controverts his view by showing that the Arran granite is actually later than the Old Red Sandstone, with which it comes into contact near Corrie.

The petrological study of Arran rocks was resumed in 1883 by Professors Judd and Cole in their memoir on the basalt glass (tachylyte) of the Western Isles of Scotland, in which examples from Lamlash (analysed by Delesse in 1858), and from the Castle grounds at Brodick, were described. In his *British Petrography* (1888), Sir J. J. H. Teall made numerous references to Arran rocks, and figured beautiful examples of pitchstone and spherulitic felsite from the island. In 1893 appeared Prof. J. W. Judd's memorable paper on composite dykes in Arran, the full recognition and description of these remarkable phenomena forming a notable advance in igneous geology. Sir A. Geikie also made numerous references to the Kainozoic igneous geology of Arran in his works on the *Ancient Volcanoes of Great Britain* (1892, 1897). G. S. Corstorphine in 1895 published a memoir (in German) on the igneous rocks of southern Arran, in which he fully described the Dippin, Auchenhew, and Levencorroch sills, a number of pitchstones, and the composite, hybrid mass of Bennan Head. He noted the occurrence of analcite in the Dippin rock, and compared the latter with the teschenite of Moravia.

In 1896 appeared Mr. John Smith's paper entitled, 'A New View of the Arran Granite Mountains.' Undoubtedly the germ of Smith's idea was contained in earlier work by Ramsay and Bryce, but his paper is notable as the first application of the study of directional features, such as jointing, slabby partings, and dyke-fissures, to the elucidation of the history of the granite intrusion. Smith believed that the undulations of the slabby jointing of the granite reflected the anticlines and synclines of the overlying schists, against which the granite was cooled and moulded ; and that the granite was finally pushed up in a quasi-solid condition along with its cover. These views are stated in more detail and criticized in Chapter XIII (p. 160).

The work of the Geological Survey in Arran began as far back as 1872, when Sir A. Geikie mapped a small portion of the north-eastern coast. The main survey, however, was not undertaken until twenty years later, when Mr. W. Gunn started mapping from the south end, gradually carrying his lines northward until he had completed the six-inch survey in 1901. His work resulted in the detailed One-inch Geological Maps, Sheets 13 and 21 (Scotland), embracing respectively the southern third of Arran with Ailsa Craig and a tiny corner of Ayrshire, and the northern two-thirds of the island, with parts of Bute, the Cumbraes, the Ayrshire coast, and Kintyre. In 1910 a special geological map of Arran in one sheet was published. A Memoir on Sheet 21 was published in 1903, and a Memoir on Sheet 13 had been partly written by Mr. Gunn when death cut short his labours.

It is impossible to praise Gunn's mapping too highly, as anyone who has had access to his six-inch MS. maps, or has studied the one-inch map of 1910, can testify. The great majority of his geological boundaries stand to-day in no need of alteration ; only interpretations need revision. His field-work was carried on under the supervision of the late Dr. B. N. Peach, and no doubt the solid, painstaking, detailed work of Gunn was often reinforced and illuminated by the inspired intuitions of Peach.

Undoubtedly the greatest result of Gunn's work was the recognition, in association with Peach, of the central ' volcanic vent,' with its enclosed fragments of fossiliferous Mesozoic rocks (*see* Chapters X and XIV), which proved the former extension of Rhætic, Jurassic, and Cretaceous rocks across Arran, and rendered certain the identification of the red and green sandstones, and ' Keuper type ' marls of the south end as Triassic, since the Rhætic fragments are associated with similar rocks in the ' vent.' Recent work has brought to light another small Lias fragment on Windmill Hill (p. 105), and, more important, masses of plateau lavas, similar to those of Mull and Skye, have been found. Renewed study of the central ' volcanic vent ' in the light of the ring complexes of Lorne, Mull, Ardnamurchan, and Skye, have shown that it, too, is a ring structure, not indeed so perfect as some of those enumerated, but with as long, complicated, and instructive a geological history.

Other results of Gunn's survey were the discovery of strata of Coal Measure age ; the identification of black slates, cherts, grits, and pillow lavas probably of Arenig age, in North Sannox ; and the discovery of five other sets of volcanic rocks in addition to that of the Arenig, and the formerly known one of the Lower Carboniferous. Two of these episodes belong to the Old Red Sandstone ; two are Carboniferous ; whilst the remaining one is represented in the Tertiary volcanic vent mentioned above.

Subsequent work has taken the form of more or less detailed study of the petrology and stratigraphy of Arran. Dr. A. Scott has begun the physico-chemical study of the pitchstones, which promises results of great value to petrogenic theory. Dr. F. Mort and Prof. J. W. Gregory have gone a long way towards elucidating the physiographic history of the island subsequent to the Kainozoic igneous episode. Prof. J. W. Gregory in 1915 set the stratigraphy of the New Red Sandstone rocks on a sure footing. The relegation of the basal red desert sandstones of this formation to the Permian has been confirmed by the discovery of an horizon in the Brodick Breccias, rich in pebbles of basalt similar to the Permian basalts of the Ayrshire mainland. The study of igneous tectonics was enriched in 1926 by Mr. E. B. Bailey's comparison of the Arran granite with the great Vredefort dome of South Africa (pp. 159, 163).

In spite of all that has been done in Arran by a splendid galaxy of famous British and foreign geologists, an immense amount of work still remains to be accomplished in elucidating the stratigraphy, petrology, tectonics, and glaciology of the island. G.W.T.

CHAPTER III

THE DALRADIAN FORMATION

THESE rocks are the oldest in Arran, and as they appear to be the continuations of the Cowal schists, they are regarded as of Dalradian age. The great granite boss of North Arran has been intruded on the line of their outcrop, so that the structural characters and stratigraphical succession of the rocks have been much obscured. The outcrop is annular in shape, forming a ring round the granite, and is interrupted only for a distance of 3 miles on the eastern side between Glen Sannox and the White Water near Corrie. Even in this region the blank is not absolute, as a thin strip of baked schists is seen near the head of the Allt a' Chapuill. The outcrop varies much in width, reaching a maximum of 2 miles at Dougrie and to the east of Lochranza. On the west side of the granite the schist outcrop comes down to the coast ; on the north-east and east, it is separated from the sea by a narrow, much-faulted strip of later sediments ; on the south it is faulted against the Lower Old Red Sandstone. G.W.T.

All the rocks to be described in this chapter have undergone some amount of deformation. They have been folded and cleaved, and mica or chlorite has been developed along the cleavage planes to a greater or less extent. The original grains or pebbles in the rock, such as quartz and felspar, have also been more or less drawn out or elongated in certain directions along the planes of foliation, so as to produce a schistose structure. Sometimes these planes of schistosity coincide with the original bedding of the rock, but very often they do not, and over considerable areas the true bedding is obscured by the superinduced structures.

In texture these rocks vary from very coarse, gritty, and pebbly varieties to fine-grained slaty rocks or phyllites. Quartz veins, often coinciding with the foliation planes, are characteristic generally of these schists, but the amount of these varies much in different places ; sometimes they are abundant, while in many districts in Arran few are to be observed. This paucity of quartz veins or the reverse, has, however, no relation to proximity to the granite, as the older writers supposed, for they were developed in the rock long prior to the intrusion of the granite. There is also great variation in the amount of mica developed in the schists. The term 'mica-schists,' under which they have been referred to, is scarcely applicable to them as a whole, seeing that mica is sparingly developed in them except in the finer-grained varieties that appear along the coasts about Imachar, Pirnmill, and Thundergay, and the more gritty varieties in the neighbourhood of Lochranza. Along this north-western part of Arran, however, the rocks have been more than usually plicated, and contain numerous quartz veins. Along the eastern and south-eastern sides of the granite mass the schists contain little mica, and are little more than schistose grits. Generally the rock is a moderately fine grained schistose sandstone, including occasional bands of a fine blue slate, and also rocks of a decidedly gritty character, schistose greywacke, and conglomerate with deformed pebbles.

Stratigraphically, the Dalradian rocks in Arran are a continuation (of course with sea intervals) of the schists on the southern margin of the Highlands which have been described in the Memoir on the Cowal district of Argyllshire,[1] and in the main they have the same north-east and south-west strike as in the Dunoon district, but with some variations due apparently to the intrusion of the granite mass. It is difficult to make out any definite order of succession over a large part of the area. The rocks are much folded on the south side of the Iorsa valley and along the west coast. To the north-east of the granite mass there is a fairly uniform dip to the south-east and east, and there appears to be a regular upward succession from the ordinary gritty schists east of Lochranza through a thick series of slates (Dunoon ?) into a thick series of alternating coarse grits and fine beds, which apparently includes in its upper part a contemporaneous volcanic group, presumably of Arenig age (*see* next chapter). W.G.

According to observations by Prof. J. W. Gregory,[2] the coarse grits underlying the lavas and slates of North Glen Sannox (? Lower Ordovician) contain pebbles and grains of the schists to the west of them ; and as these pre-lava cleaved grits and associated phyllites are identical with the grits and slates occurring in alternating bands on the north side of Glen Chalmadale, the schists lying unconformably beneath them must be still earlier in age, and almost certainly Dalradian.

In proximity to the granite the general south-west strike of the Dalradian rocks is usually much changed. As Mr. E. B. Bailey[3] has shown, the schists in most places have been bent up into parallelism with the granite margins, so that on the south-west and north-east sides of the granite strike lines of the schists take a right-angle twist as they approach the igneous contact (Plate III). This abrupt change of strike can be easily followed on the slopes above Whitefarland. On the north-west side a beautiful synclinal structure has been developed, which is finely exposed on the shore north of Catacol Bay. Traces of the synclinal structure first appear near Rudha Bàn north of Pirnmill. The syncline extends from Catacol, right through Lochranza, and reappears on the Newton side. On the south-east side of the granite the schists are already tilted to the south-east away from the granite margin, and no change in strike or dip has resulted from the intrusion.

The schists are baked hard and hornfelsed for a distance of from 100 to 300 yards from the granite margins, and near the actual contacts the foliation becomes very obscure or is completely obliterated. As the rock is more resistant than the granite itself it occasionally forms a ridge at a higher elevation than the granite immediately adjoining. This is finely shown in Glen Catacol and Glen Easan Biorach, where the streams have cut narrow gorges through the altered schist. A short account of the contact metamorphism effected by the granite is included on a later page (p. 156).

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[1] 'Geology of Cowal,' *Mem. Geol. Surv.*, 1897.

[2] J. W. Gregory and G. W. Tyrrell, 'Excursion to Arran,' *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, p. 404.

[3] 'Domes in Scotland and South Africa : Arran and Vredefort,' *Geol. Mag.*, vol. lxiii., 1926, pp. 481–495.

G.W.T.

Detailed Description.—To the east of Glen Rosa there is a good exposure of schists all over Glenshant Hill. In the Cnocan Burn, below the mill dam, the true dip of the schists is to the south-east or south-south-east at a high angle, and the foliation dip is there coincident with that of the bedding. The rocks are mostly gritty and some are pebbly, and this type of schist prevails nearly all over Glenshant Hill. In Creag Rosa some alternations of thin, gritty, and slaty bands show that the beds are vertical with a north-east strike. To the north-west of this the foliation strikes in one place to the north-north-east, while the bedding strikes east-north-east, so that the true dip is at a high angle to the south-south-east. Near the granite these rocks are considerably altered, and appear to be more contorted than usual. Much of the same type of schist prevails on the opposite side of Glen Rosa, about the hill called Cul nan Creagan, where thin quartz veins occur occasionally in the rock. In Gleann Easbuig, east side, and 950 yards north from the top of An Tunna, is a very coarse pebbly band of a slightly greenish tinge, which is about 30 feet in thickness. The deformed pebbles are of quartz and felspar, set in a slightly chloritic matrix, and the rock which contains them may be traced in a direction slightly north of west for about 200 yards, cutting across the foliation of the ordinary schist nearby. There is much gritty schist on the north-west side of Gleann Easbuig, but no rock so coarse as that described above was noticed there. On the hills called Beinn Chaorach and Beinn Lochain to the south of the Iorsa valley the schists are generally so plicated that it is difficult to make out any prevailing strike. Much of it is fine grained, with quartz veins. On the north side of the Iorsa the rock is altered by the granite, and the foliation rendered obscure in many places, the most prominent planes being joints, which seem the result of the granite intrusion. The rocks are well exposed in the lower part of Glen Scaftigill, and in the adjacent burn of Allt na h-Airidhe. In Glen Scaftigill the schist is moderately fine grained, and bluish or grey in colour; the foliation is generally even and regular with little contortion and few quartz veins. The foliation dip is to the south or south-south-east at a high angle; sometimes it is vertical, while the bedding as seen distinctly in one place strikes north-east, and dips steeply south-east. The foliation at this place dips south-south-east. To the westward, about Cnoc Donn and between this hill and Dougrie Point, there is a strong band of gritty rock which is very slightly schistose, and is apparently overlying a thick band of black, bluish, and grey phyllitic schist, which is much contorted. Some very coarse and pebbly bands of the gritty rock are exposed in the old sea-cliffs three-quarters of a mile north of Iorsa Foot, and the contorted slaty rock is exhibited in many places to the south-east of Balliekine. Alternations of gritty and slaty schists, very much plicated, appear along the shore between Balliekine and Imachar, and opposite the latter place the schists are more than usually contorted, with abundant veins of quartz. On the hills nearly a mile east-north-east of Imachar alternations of pebbly bands with rocks of a finer grain show that the strike of the foliation is from 10° to 15° farther west of north than that of the bedding. Both are practically vertical. North of Allt Gobhlach, along the shores of Penrioch (Penrioc) and Auchmore, the schists are not so much plicated, but numerous faults crossing the alternations of fine and coarse rock are exposed on the shore. At North Thundergay, again, the rocks are as plicated as at Imachar. There are some very coarse bands about Penrioch, but they are usually thin and cannot be traced far. One of them contains pebbles from 2 to 4 inches long. There is also, east of North Penrioch, a band of light-coloured, schistose, micaceous limestone 4 or 5 feet thick, which was formerly quarried and burnt for lime. It can be traced for a considerable distance to the northward. Some other very thin calcareous bands are intercalated in a dark-coloured schist.

In the lower part of the Pirnmill district the schist forms a remarkable series of ridges and hollows nearly coincident with the strike ; higher up the hillsides other marked features are apparently due to joints or faults, as their direction makes an angle with the strike. Near the granite the schist is much hardened, and the finer varieties assume a bluish colour. A marked set of joints appears also to have been developed in this altered rock by the action of the granite. These joints are in places much more prominent than the foliation planes, which are nearly obliterated.

On the north side of the stream Allt nan Eireannach, nearly half a mile south-south-west of Catacol Bridge, there occurs a beautifully glossy, gritty mica-schist with abundant sericite mica on the foliation planes. Along a great part of this burn runs a thick band of dark slaty schist, which is probably identical with that which appears near the foot of Abhainn Bheag on the east side of Glen Catacol. And there is strong probability that the same band continues southward from Glen Catacol nearly parallel to the boundary of the granite, but at no great distance, as far as the Allt Gobhlach opposite Pirnmill.

North-westerly dips prevail in the schists in the district between Catacol and Pirnmill, though, of course, there are many minor folds parallel to the general strike. On the eastern side of Catacol Bay there is a marked synclinal fold, which runs nearly parallel to and not far from the coast. The line of it crosses the loch a little north of Lochranza Castle, and it can be observed for some distance east of the loch but gradually disappears, so that from North Newton there seems to be a regular and apparently ascending series in the schists all along the edge of the high ground to the south-eastward as far as to Corloch, where we come upon the supposed Arenig lavas. On the shore at North Newton, where the rocks have a high dip to the south-south-east, the schists are gritty, somewhat greenish and chloritic, with alternating bands of finer slaty schist, more micaceous or chloritic, and with more abundant quartz veins. Some bands outcropping to the east of the hamlet are very strong and coarse. Variable rocks of more or less gritty character prevail over Cnoc nan Sgrath and Torr Meadhonach till, near the road leading to the Cock, we come upon the edge of a thick slaty series, in which there are two old slate quarries about a quarter of a mile south of the road. In the larger and more easterly quarry there are rather coarse and thickly laminated bluish slates with some pale coloured or greenish, probably chloritic, bands. The slates are not glossy, and there is not much mica on the foliation planes. Dark bluish, fine slaty schist with quartz veins appears in Creag Ghlas Cuithe at the edge of the high ground, where the dip is almost due south. In Glen Chalmadale the dip is eastward, and between these two localities the strike describes a curve of a quarter of a circle. This slate band is most probably the Dunoon series described in the Memoir on the Cowal district. To the eastwards succeeds a strong, coarse, and thick gritty mass, which is probably the Kilcreggan series. It is a very massive grey and greenish greywacke, only slightly schistose, the bedding of which is as even and as regular as a sandstone. In one place there is interbedded a few feet of greenish slaty rock, which much resembles the Green Beds in character. Pebbly bands are common in this rock and show the bedding clearly, which dips from 30° to 50° east-south-east. This rock forms a very fine set of crags, some of which are bounded by straight faces running nearly across the strike. They appear to be due to joints, along which the rock has parted, and masses have fallen away. In the upper part of this series are alternations of slaty and gritty beds which give rise to strike features crossing the line of crags. These pass up into a greenish slaty series which forms the highest ground at the Ordnance Station 1453, and this is the highest point attained by the schists in the island. About half a mile south of this the gritty series below forms crags at Creagan a' Choilich, where a very coarse, pebbly, quartzo-felspathic band may be seen. Eastwards from the Ordnance Station another thick gritty series comes on above the finer band, the upper part of it being marked by a very coarse, quartzose pebbly band 100 yards in breadth. In various places along the course of this band it may be observed that the true dip as shown by the quartz pebbles is high, sometimes nearly vertical, while the planes of schistosity or foliation dip about 30° or 40°. At the southern exposure of this band there is a cross fault which shifts it westward 100 feet or more. The crag here is visible at long distances. The pebbly quartzose rock is white in colour, and is penetrated by conspicuous white quartz veins. A portion of the rock might be described as a conglomerate. Another band of dark and bluish slaty schist succeeds to the eastwards, and is some 200 yards across, but is little exposed except on the crags; and then comes a gritty series, variable in character and half a mile wide, which continues till we arrive at the so-called Arenig traps. W.G.

CHAPTER IV

(?) ARENIG ROCKS

A STRIP of rocks that may be separated from the ordinary schists of the island is found in North Glen Sannox. It crosses the valley from south to north at a distance of rather over a mile from the sea. It is upwards of a mile and a half in length, and its width varies from 100 to 400 yards, being narrowest at its northern end. The rocks in this area, so far as can be ascertained, are not separated by any structural line from the ordinary schistose grits on either side of them, and they appear to be essentially a part of the metamorphic series of the Highlands. They differ much in character, however, from ordinary schists, in that they consist mainly of igneous rocks, both volcanic and intrusive, with which are intercalated bands of black shales or schists, and thin bands of chert.

The black shales and cherts are associated together, as they are in the Aberfoyle district along the Highland border, and in the band of similar deposits intercalated with volcanic rocks in the Arenig group of Ayrshire. The black shales are partly in the condition of phyllites, and are much contorted in places. The cherts are perceptibly granulitized, and in structure similar to those parts of the cherts which have been altered by the granite of the Southern Uplands. When in this condition, such rocks have generally lost all trace of their organic remains, and no radiolaria have yet been found in these Arran cherts. The most prominent members of this group of rocks are those of igneous origin, and it is now definitely ascertained that there is in Arran a very old volcanic series which includes undoubted lavas and volcanic tuffs. The lavas form bands of a dull-green, fine-grained rock, which may be conveniently spoken of as 'greenstone.' Like their associated sediments they have undergone a considerable amount of deformation, and are now in the condition of epidiorite. The whole of the rocks, both aqueous and igneous, appear to be in the same state of metamorphism as the schists to the east and west of them. They have an apparent dip to the east-south-east at high angles, and sometimes are practically vertical, and it is by no means certain which is the top or bottom of the series. They have also undergone much plication, which is particularly observable in the intercalations of black schist, and, as has been before observed, they are flanked on either side by schistose grits of the ordinary Southern Highland type.

The strip of rocks thus defined is truncated at its southern end by the intrusion of Arran granite at the north-east end of the ridge of Suidhe Fhearghas, while its northern boundary is a fault which brings down against it a part of the Lower Carboniferous Series. The Schistose grits, which apparently underlie these rocks, are well exposed in the North Sannox Burn at the bridge, while another series of schistose grits, which apparently overlies these volcanic rocks, can only be observed in the main stream and on the south side of the glen, as they are cut out on the north side by the Highland border fault, which brings down the Lower Old Red Sandstone against the igneous rocks. This fault gradually crosses the line of strike of the igneous group, so that only the lower portion of it is represented at its northern end.

The general succession of the members of this group of rocks, together with the underlying and overlying sedimentary strata belonging to the Highland schists, is apparently, in descending order, as follows :—

1. Coarse schistose grits or gritty schists, grey in colour, and weathering with a smooth surface.
2. Thin bands of slaty schist, with traces of dark schist or shale, apparently alternating in places with thin bands of greenstone.
3. Upper bed of greenstone, generally fine grained and quite schistose in places, with some lenticular bands of agglomerate.
4. Bands of light-coloured and dark chert, associated with bands of laminated black shale or schist. Lenticular bands of volcanic tuff and of schistose grit also occur on this horizon.
5. Lower bed of greenstone, often massive. It contains an agglomerate band on the north side of the valley.
6. Bands of black shale or schist, associated with chert, and with some fine-grained slaty schist. There are traces of agglomerate also.
7. Thick mass of strong and coarse schistose grit, sometimes greenish in colour and generally different in character from No. 1.

The whole succession may be observed in the North Sannox Burn, and on the hillside to the southward. On the north side of the glen the upper grit and greenstone are obscured by glacial drift for some distance till they are cut off by the Highland fault. Nos. 2 to 6 embrace the rocks supposed to be of Arenig age.

W.G.

Another reading of the section in the North Glen Sannox Burn, taken in the same direction, is given below. It varies in detail, but corresponds well in essentials with that worked out by the late Mr. W. Gunn.

Starting at the eastern margin of the outcrop, and proceeding westward, the coarse quartz-conglomerate of the Lower Old Red Sandstone is succeeded, after a blank interval, by dark, bluish, not much altered schistose grits, abundantly intersected by quartz veins. The prevalent colour of these rocks is blue, and they weather with very smooth polished surfaces in the stream bed. These rocks correspond to No. 1 of Mr. Gunn's section, and are not included as belonging to the Arenig.

Farther west there are quartzose and slaty bands of a greenish colour dipping at 70° to the east-south-east. These rocks are interbedded with a few bands of rather more argillaceous green slates, and a bed of red and green jasperoid mudstone. These rocks are regarded as the uppermost beds of the Arenig section, and correspond to No. 2 of Mr. Gunn's section above.

Beneath these rocks comes a band of hard greenstone marked with dark spots (the 'spotty lava'). This is the upper lava (No. 3) of the above section.

At the bend in the stream near 138 feet O.D., a quarter of a mile E.N.E. of North Sannox Bridge, there is a thick band of striped, blue, argillaceous slates, with some coarser gritty bands which resemble ash beds. These are underlain by coarse angular breccias mainly composed of fragments of spotty lavas. The dip of these beds is nearly vertical, and their outcrop is about 25 yards wide. This is No. 4 of Mr. Gunn's section.

Then comes the main band of lavas (No. 5). They are green compact rocks, smooth-weathering, and for the most part devoid of the spots characterizing the upper band. The pillow structure is here best exhibited. The pillows are rather small, averaging only 12 inches in diameter, and are often crushed together. Mr. Gunn's acute observation of the chilled margins of the pillows, and their concentric bands of amygdales, to be discerned in spite of the crushing and alteration the rocks have undergone, was confirmed. At the base of the lavas is another thin bed of breccia, underlain by blue banded slates and slaty grits, in which are occasionally intercalated beds of blue schistose grit. This represents No. 6 of Mr. Gunn's section, and is the base of the series recognized as Arenig.

At North Sannox Bridge are alternations of fine-grained grey and green-banded siliceous slates or slaty quartzite (siltstone), coarse quartzite with only a faint schistosity, dark green schistose grits, and green slates. Above the bridge coarse schistose grits become the dominant rocks of the section. The prominent crag to the south of the bridge is composed of the lower band of lavas, which are here frequently vesicular. In the crag higher up and farther to the east the spotty lavas of the upper band are encountered, and are followed by shattery green slates, which are interbedded with a band or two of spotty lava and with coarse schistose grit. The latter becomes the dominating rock east of the little stream descending from Torr nan Gobhar, and continues up to the boundary with the Old Red Sandstone conglomerate. G.W.T.

Details of Sections

The gritty schists, No. 7, are well exposed in the stream where the road to Lochranza crosses, both above and below the bridge. They are here crossed by some basalt dykes. About 70 yards east of the bridge the coarser rock contains a band of fine-grained schist, and 80 yards farther down the stream dark schists are seen to be associated with a brecciated rock like that which occurs in several places. It is composed of fragments of old lava, but is not exactly like a true volcanic agglomerate, and may have been produced by the brecciation of igneous rock in motion before final con solidation. Above these rocks in the main stream comes the lower mass of lava (No. 5), which occupies the burn for 100 yards. It is for the most part a massive rock, moderately fine grained, and of a greenish-grey colour. It exhibits well-developed 'pillow structure' identical in character with that of the basic lavas of Arenig age in the Southern Uplands, but not on so large a scale. The chilled and rounded margins of these ‘pillows,’ and the numerous amygdales that are found a short distance inward from their surfaces are marked features. The dark schist that apparently overlies the pillowy lavas is much contorted in places, and is accompanied by a breccia or agglomerate similar to that previously described in No. 6, and also by some thin lava-like bands. The cherts that are associated with the black schists are well exposed about 200 yards up Allt Cairn Bhain, a small stream on the north side of the glen. Some of them are dark in colour, but the thickest and purest bands seem generally to be grey or light-coloured. High up on the south side of the valley there is associated with this black schist a strong gritty band, and immediately upon this rests the upper greenstone, No. 3. In the main stream this is but occasionally exposed, and the best sections of it are on the hillside to the southward. It much resembles the lower bed, but the pillowy structure is not so prominent. In its upper part the rock is often so schistose that it might be taken for the so-called ‘green beds’ of the southern Highlands. There is a good exposure of this upper lava on and about the two small hills called Cnocan Donna, where the doubtful Arenig rocks attain their highest point above the sea (944 feet). On each of the knolls a band of true agglomerate is interbedded with the greenstone. These bands are lenticular, and are made up of large angular fragments of fine-grained lava. Neither of them can be traced for more than 40 or 50 yards along the strike, and the more southerly is not more than 6 feet across at its widest part. The other is larger, and probably as much as 30 feet across in its broadest part.

The upper schistose grits, but partly exposed in the main stream, are a prominent feature on the hillside to the southward, where they form a strip of ground 200 yards in width. They can be followed in this direction along the strike to the eastward of Cnocan Donna till they in turn are cut off by the granite.

The lower greenstone forms prominent crags, one of which, about 300 yards south-south-east from the bridge, is a conspicuous object from the road. The same rock forms crags at Corloch, at the northern extremity of the area, and all the crags on the north side of the valley between Allt Carn Bhain and Allt Dornach, the next small stream to the west.

There can be little doubt that these bands which we have called greenstone are true lavas, and they show many points of resemblance to the lavas of the Arenig volcanic series of Ayrshire.

Two specimens from these doubtful Arenig lavas were sliced and submitted to microscopical examination by [Sir] J. J. H. Teall. One of these from Cnocan Donna on the south side of North Glen Sannox, was found to be a fine-grained, greenish-grey, massive rock (8666) composed of minute prisms of nearly colourless hornblende, epidote, leucoxene after iron-ores, quartz, and chlorite.

It is evidently an altered basic igneous rock, a variety of epidiorite.

Another specimen (8667) from Torr na Lair Brice on the north side of the glen is a scoriaceous rock, the cavities of which have been filled by calcite. The main mass is formed of microlitic felspar, chlorite, leucoxene, and carbonates. It is an altered basic rock, but differs from the first in having recognizable felspar. It is closely allied to, but not identical with, the common forms of pillow lavas.

These two fine-grained rocks are highly altered greenstones, allied to those found in association with cherts in other areas.

Later some additional specimens were cut, and the slices were described by [Sir] J. S. Flett. Three of these (9381, 9382, 9383) from Torr na Lair Brice, 550 yards N.E. of North Sannox Bridge, though differing somewhat in individual characters have a general resemblance to those described by [Sir] J. J. H. Teall. A specimen (9384) from a small burn on the south side of the glen opposite Allt Cairn Bhain is rather peculiar, being a grey-green rock with brown streaks and patches. It is a fine-grained basic igneous rock which has undergone much deformation. There is a band of this rock along the strike, and it may be seen also just south of the main stream. Two specimens of the supposed lavas altered by contact with granite (9385, 9386) are very different from the rest, and one of them (9386) appears to have lost all trace of its igneous origin (can it be altered black shale ?). The last of these new slices (9387) was taken from a fragmental rock of a tuffaceous character in the upper part of Allt Cairn Bhain. Many of the fragments are fine grained and not certainly igneous, but the band from which the specimen was taken is several feet thick and the coarser parts contain undoubted large fragments of the lavas. This band is associated with the black schists.

Intrusive Igneous Rocks, probably of Arenig Age

At a distance of 600 yards north from the main stream in North Glen Sannox, and near Allt Dornach, is a rock which differs considerably in character from the lavas. It is coarser grained than these, and was probably a hornblende-gabbro originally. It was the first of the igneous masses to be noticed in this area, and from the way in which it is associated with ordinary schistose rocks of a clastic origin it was regarded as an intrusive rock, which view has subsequently been corroborated by the result of a microscopic examination and also by its similarity to undoubted intrusive rocks associated with the Arenig lavas of Ayrshire. It forms a band some 15 to 20 yards in width, which is about 50 yards east of the small stream mentioned, and on the west side of the bedded lavas, and separated from the latter by a considerable band of black schists with chert. The intrusive band, however, as given above, includes some lenticular and irregular strips of schist. The best section occurs a few yards below the old track or road which was formerly the highway to Lochranza, and the intrusive rock there forms a small crag, but it cannot be traced far either way. A rock of a somewhat similar character is found on the west side of Allt

Cairn Bhain (the next small burn to the east) between 100 and 250 yards north from the main stream of the glen. W.G.

These rocks are probably closely related to the large mass of epidiorite or hornblende-schist at Scalpsie Bay in Bute.[1]

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 22. W. R. Smellie, 'The Igneous Rocks of Bute,' *Trans. Geol. Soc. Glasgow*, vol. xv., part iii., 1916, pp. 336–338.

CHAPTER V

THE OLD RED SANDSTONE

As a whole the Old Red Sandstone occupies a semicircular strip of country stretching from the Fallen Rocks 2 miles north-north-west of Sannox Bay to the west coast of the island. It passes between Corrie and the eastern margin of the northern granite, through Glen Rosa, and then turns westward following the southern margin of the ring of Dalradian schists, thus reaching the western coast south of Dougrie. The average width of this annular strip is about 1 mile (*see* One-inch Geological Map of Arran). The outcrop has a large bulbous extension to 3 miles south of the String Road, but the greater part of this mass has been obliterated by, or rather, incorporated into, the Central Ring structure.

The formation consists of two divisions, Lower and Upper, conforming to the general classification of the Old Red Sandstone in the Caledonian basin of deposition. There must be an extensive stratigraphical gap between the two formations, but there is singularly little direct evidence for unconformity. This may be partly because of the prevalent high dips, and partly because there is no abrupt change in the characters of the sediments. Gunn has written (MS. notes) that the rocks of the lower division are more felspathic than those of the upper, and their colour is not so bright a red. When the rocks are altered by contact with intrusive igneous rocks, as they so often are, the beds of the lower division become hard and grey in colour, while those of the upper division, which are more quartzose, turn white ; and this difference assists materially in drawing a boundary line which is often otherwise obscure or conventional.

The boundary between the Lower Old Red Sandstone and the underlying schists is everywhere faulted ; and even where the formation comes into contact with the northern granite, as it does near Corrie, Mr. E. B. Bailey has shown that the boundary is faulted to such an extent that a band of mylonite has been formed,[1] as, for example, in the White Water junction. Around the Central Ring structure the Old Red Sandstone has a normal intrusive contact, very much shattered and interpenetrated, with the Kainozoic gabbro, granite, and felsite. In general the Upper Old Red Sandstone passes with perfect conformity of strike and dip into the basal beds of the Carboniferous.

THE LOWER OLD RED SANDSTONE

The greater part of the area outlined above is occupied by the lower division of the Old Red Sandstone, which always appears on the concave northern side of the semicircular outcrop, next to the schists and granite. The formation is well exposed in North and South Glen Sannox, in Glen Rosa, and in the burns immediately to the north of the String Road. There is also a good section towards the head of the Clauchan Glen on the south side of the Central Ring area.

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[1] E. B. Bailey, *Geol. Mag.*, vol. lxiii., 1926, p. 486.

The sediments seen in North and South Glen Sannox consist of coarse conglomerates, red mudstones, and purplish or chocolate-coloured felspathic sandstones, and they may serve for a general description of the lithological types occurring in the formation as a whole. The blocks in the conglomerates are well rounded. and many of them are of a pinkish or white quartzite, often associated with pebbles of andesite derived from the denudation of lavas belonging to a lower part of the formation. The conglomerates are associated with, and alternate with, beds of red or purplish fine sandstone and mudstone; they generally form the lowest and most westerly part of the formation as exposed in these glens. The middle portion is composed largely of mudstones and flaggy sandstones, and the higher part is mainly felspathic sandstone, somewhat coarser and thicker-bedded than that in the middle part.

Around the Central Ring area, especially in the Clauchan Glen, and at the head of Glen Dubh, the Lower Old Red Sandstone has been greatly altered by the heat, and also by emanations, from the adjacent igneous centre, so that now they are totally unlike Old Red Sandstones in character. They are, in fact, more like old Silurian greywackes, very hard and tough, and of a bluish-grey colour. They are also apparently contorted in places, and the bedding cannot always be determined.

Where the outcrops are small, and broken up by faulting or igneous intrusion, these altered rocks often cannot be traced into the normal reddish and purplish sediments; and as there are at least three series of sandstones and shales outcropping in the vicinity of the eastern edge of the central igneous area, it is often a matter of perplexity to assign the altered rocks to their correct formation. This is particularly the case at the heads of Glen Dubh and Glen Ormidale.

A related type of alteration, although not by direct contact with igneous magma, is to be found in the Lower Old Red Sandstone near the head of the Merkland Burn, north of Brodick, at least half a mile distant from the margin of the northern granite. These rocks are indurated and epidotized, and seem to represent an area through which emanations streamed from the neighbouring granite. This region is more fully dealt with below (p. 35).

High easterly or south-easterly dips are prevalent in the Lower Old Red Sandstone over the eastern and southern part of its outcrop. Dips to the S.S.W. and S.W., however, prevail in the extreme west near Auchencar. The easterly dips are mainly to be found in the outcrop near Sannox on the east coast. Hence there is some evidence of a radial disposition of the dips outwards from the northern granite mass, as if a dome-shaped elevation had been caused by the intrusion of the granite. G.W.T.

Stratigraphical Details

A great series of purplish-red and chocolate-coloured sandstones, generally hard and micaceous, and often thin-bedded, occupies Glen Shurig and strikes south-west, with a high dip to the south-east, across the String Road. These rocks have been quarried in places for road metal. They form, apparently, the highest portion of the lower division of the formation. As the dip is high, they must be between 2000 and 3000 feet in thickness. Although in places the dip is reversed there are no apparent contortions, so that the strata are probably occasionally inverted, as they must be in the Cnocan Burn and on the west side of Glen Rosa. It was in this group of rocks in Glen Shurig, in a burn near the String Road, that Sir A. Geikie and his students found a specimen of *Psilophyton* in the year 1882. From the same upper part of this subdivision in Glen Shurig about a dozen specimens of plants were obtained by Messrs. Macconochie and Tait, the fossil collectors of the Geological Survey, in 1897. Dr. Kidston, to whom these were submitted for examination, could only identify one of them specifically as *Psilophyton princeps*, var. *ornatus* Dawson. He thought, however, that all the other specimens belonged to this species, which is characteristic of the Perthshire and Forfarshire Old Red Sandstone, and is not known in the Caithness Flags. The strata in which these plants were found are hard, purplish, flaggy, micaceous sandstones, often weathering to a yellow tint, and they must be several hundred feet lower in the formation than those which yielded *Psilophyton* in 1882, but both belong to the same set of beds. The exact locality for the specimens collected by the Geological Survey in 1897 is in the main stream of Glen Shurig, about 200 yards above its junction with Allt Mòr, which is its principal tributary on the south side. In the south bank of the stream at this point is a good shale band about 3 inches thick, and it was from this bed that the plants were obtained. Some fragments were also got on a somewhat higher horizon, some 100 yards lower down the burn and nearer Allt Mòr, and it was in Allt Mòr itself, but some distance up from its foot, that the specimen was obtained in 1882.

The thick masses of mudstone, interstratified with coarse conglomerates made up mainly of quartzite pebbles, so conspicuous in North and South Glen Sannox, are much attenuated in Glen Shurig, while the upper felspathic sandstones are much thicker.

W.G.

A good section in the Lower Old Red Sandstone is exposed in the Allt an Bhrighide, a northern tributary of Glen Shurig. Vertical chocolate and red fine-grained sandstones are seen to the north of West Glenshurig. Higher up, near 674 feet O.D., and just at the corner of the wood, there are fine exposures of coarse andesitic breccias, and associated dark sandstones which look like tuffs, but are probably due to the denudation of an andesite lava area of earlier date. Above these igneous breccias comes a great thickness of typical torrential quartz- and quartzite-conglomerate, interbedded with fine-grained chocolate-coloured sandstones, and coarse, gritty, pink sandstones. The strike ranges from north-west to north, and the rocks in general have a vertical attitude.

In Glen Rosa, near the schists, at the sharp bend in the burn below Coire Fhraoich, a type of Old Red Sandstone is seen which approximates in character to the 'doubtful rocks' of the Merkland Burn, and the contact-metamorphosed types. Its colours are grey and green, not red and purplish. The rocks consist of coarse grits and fine conglomerates rich in small quartz pebbles, subordinate sandstones, and thin bands of slaty mudstone. All the rocks are altered and indurated, and the grits are epidotized. The strike is N.N.E. and the dip between 70° and 80° to the W.N.W. Where the Glen Rosa path crosses a tributary which joins the burn practically at the above-mentioned angle, there is a visible junction between the Old Red Sandstone and the schistose grits and slates. As the schists strike N.E. there is a discordance of strike of about 30° between the two formations. According to Gunn [1] similar rocks occur near the schists in Garbh Allt, north of Monyquil. Apparently most of the exposures of Old Red Sandstone near the granite margin will be found to be affected in some degree by the igneous emanations. G.W.T.

East of Dougrie there are fine sections in the Old Red Sandstone on the shore and in the old sea-cliffs, but a portion of the rocks there exposed probably belongs to the upper division of the formation. The Lower Old Red Division, which is characterized by thick bands of coarse quartzite-conglomerate, alternating with red and purplish sandstones, must in places on this side of the island have a thickness of several thousand feet, with a high southerly dip ranging from S.S.W. to S.S.E. The coarse conglomerate forms a broken ridge of high ground east of Auchencar, and is apparently unusually thick in the hill of Garbh Thorr, near Monyquil, which is probably bounded on either side by a large fault. Below this mass of conglomerate is found a volcanic zone, composed of lavas some 50 or 60 feet thick, which is elsewhere described (p. 36). These crop out in Auchencar Burn, to the north of the hill Baniorlach, 1¼ miles farther east, and to the north-west of Garbh Thorr. Below this zone the rocks consist mainly of sandstone. The sandstones which overlie the conglomerate, mostly thin-bedded or flaggy, are exposed in the Machrie Burn, west of Cnoc na Ceille.

The boundary between these undoubted Lower Old Red Sandstones and the beds above which may belong to the upper division of the formation, is somewhat arbitrary and uncertain, as the dip and strike of the two set of rocks are, on this side of the island, everywhere the same, and no fossils can be obtained to assist us in the determination of the exact line. In the old sea-cliff, near the Dougrie schoolhouse, more than half a mile north of Auchagallon, there is a variegated marl bed covered with oval or round white and greenish spots, and there are also narrow bands of the same material along joints, some of which are also lines of movement. This bed, which is 12 to 15 feet in thickness, with some irregular sandstone on one side, contains doubtful traces of plants. This band is included in the lower division, and the rocks above are referred doubtfully to the upper or middle division. Similar greenish marl bands are found along the strike in the Machrie Burn, and in a smaller burn farther east, and some much thinner bands of the same kind also occur in the Machrie Water, so that the line given on the map seems to follow a definite horizon, if it is not an actual boundary between two sub-formations. Below these bands in the Machrie Water the rock is much hardened and jointed, for which alteration there is no visible cause except an intrusive basic dyke. W.G.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 24.

The Lower Old Red Sandstone occupies a considerable area in the region about the head of the Clauchan Glen and Cnoc na Croise (1346 feet), to the south of the Central Ring structure. The exposures are not very good, and occur principally in the Clauchan Burn, and in the lower part of a small tributary which enters the main stream north-west of Cnoc a' Chapuill. In the latter stream the rocks are much baked, and the bedding is obscure and in some places apparently destroyed. Near the foot of the burn, bluish and purplish mudstone dips to the south at 45°, but higher up come bluish-grey rocks with no appearance of bedding. They seem to be altered grits and mudstones, shattered in places; and are cut by occasional basic dykes. Near the base of the upper division appears a mass of conglomerate with a high dip to the south. The rocks crop out in places to the east of this burn, but the ground is generally obscure. Beds of grey grit and dark-grey mudstone, thin grey grit, and greyish pebbly felspathic sandstone with a dip east of south, between 30° and 60°, are seen only occasionally. About 200 yards west of the foot of the small burn, a section appears in the south bank of the main stream. The rock is a blocky grey felspathic pebbly grit which just appears under a thick mass of boulder-clay. A grey or purplish grit of a somewhat similar character crops out about 100 yards farther west, and dips S.S.W. at an angle of 25°, while 200 yards farther down, and still on the south side of the stream, are reddish, purple, and grey hard felspathic sandstones, dipping S.S.W. at 20°. Somewhat farther west the sandstone is brecciated, with clayey galls in places; and at this place is drawn the line between the two divisions of the formation.

W.G. (MS.)

Altered Rocks.—In the upper part of the Merkland Burn, outside the Castle woods at Brodick, there are some rocks of a peculiar type in this division. Near the edge of the wood, but inside, conglomerates with well-rounded pebbles of the true Lower Old Red type may be observed in a vertical position and with a northerly strike. Succeeding to these, outside the wood we find sandy red mudstones in the stream for 100 yards. They have the same vertical attitude as the conglomerates, but the last visible strata of this kind have a strike directed somewhat west of north. These rocks are abruptly truncated at a waterfall by a totally different set which come on along a line running about north-north-east. The junction line may be a fault, and the rock which we first come to on the other side has somewhat the appearance of a dyke a few feet in width. North of this we seem to have recognizable purplish mudstones, altered, however, with another possible green dyke parallel to the stream on the west side. Below the first branch stream on the west side there appear to be fairly recognizable altered mudstones striking north-east and dipping south-west. All these rocks have a number of yellowish-green veins and patches of epidote.

For a long way above this, in the main stream, is a mass of apparently fine-grained blue-grey rock with very indistinct traces of bedding, and not at all resembling the ordinary type of Old Red Sandstone. Similar rocks may be seen in both the branch streams on the west for a distance of about 200 yards up them, where rocks of an undoubted gritty character appear. In the upper branch stream this is a white hard-baked sandstone, almost a quartzite, which has evidently undergone considerable alteration. This has been microscopically examined by Mr. Kynaston, and is seen to consist principally of numerous small rounded grains of quartz and felspar, some of which is microcline and some plagioclase. The interstitial material often has the appearance of a fine quartzose mosaic, as if it had been recrystallized, but the larger grains show no perceptible alteration. There are some grains of epidote. The highest observed rock in the main stream, 700 yards above the wood, is clearly an altered sedimentary rock, a rather coarse grit with numerous fragments of andesite, more or less rolled, quartz-grains, felspar, epidote, etc.

Some specimens from this locality, however, are very like felsitic tuffs or agglomerate, and some of the fragments have points of resemblance to the salite-diabase of Glen Rosa. But it must be remembered that in places the undoubted Lower Old Red conglomerates are largely made up of fragments of old basic lavas. Mr. Kynaston, however, examined and reported on some thin sections cut from the rocks as well as some undoubted Old Red rocks from the immediate neighbourhood, and inclined to the view that they are of pyroclastic origin, of the nature of tuffs or agglomerates.[1] One of the specimens sliced was the supposed dyke at the edge of the mass, which is a fine-grained dark rock, apparently of a massive character. Under the microscope, however, it appears partly andesitic, and in a more or less fragmentary condition, and partly consists of small fragments of quartz and patches of calcite in a fine matrix. It is difficult to determine the exact nature of this rock, and it seems possible that it is essentially a massive rock which has been broken or crushed along or near a line of fault, which may be of later date than the alteration surrounding the doubtful rock, for there is no trace of such alteration on this side in the Lower Old Red mudstones.

These doubtful rocks cannot be observed in the drift-covered and peaty ground east of the main stream, but they would appear to be comprised in an oval area which is about 500 yards in length from north to south. As the rocks of this area differ so much in character from the genuine Lower Old Red Sandstone of the neighbourhood, and as they have many points of resemblance to tuffs or agglomerates of pyroclastic origin, it seems more probable that they belong to the latter class. It will be most convenient, then, to consider this small area as the site of a volcanic vent in the Lower Old Red Sandstone rocks, the age of the vent or the period when there was outpouring of either lavas or tuffs being still to be determined.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 173.

There remains to be considered the undoubted alteration in the surrounding rocks ; at all events on the western border of the area. The large mass of granite suggests itself as the cause of the alteration ; but the edge of the granite is half a mile distant, and metamorphism in the surrounding rocks cannot be traced so far away from its mass. Often in the case of the Old Red Sandstone it only extends some 40 or 50 yards away from the boundary. On the contrary, the evidence, so far as it goes, favours the view that the alteration in the surrounding rocks came from within the doubtful area itself, and it seems extremely probable that the operating causes were gaseous exhalations and emissions of heated aqueous vapour in connection with a solfatara. W.G.

The type of alteration described above seems to have been of the same nature as that which is to be observed in the Old Red Sandstone at numerous places around the northern granite and the Central Ring Complex. At the head of the Merkland Burn, however, the alteration seems to have affected sandstones and conglomerates made up, as the Old Red Sandstone is elsewhere, of andesitic and other lava detritus. Hence the resemblance to tuffs and agglomerates which Mr. Kynaston noticed in the appended petrographical descriptions :[1]

'7541. Merkland Burn, west branch, 500 feet above junction. A dark greenish rock, in which numerous small irregular fragments are easily seen with the naked eye. The microscope shows numerous small fragments of andesite and felsite (?) up to about an eighth of an inch in diameter, broken plagioclases, and quartz grains, grains of epidote, chlorite, etc., in a fine matrix consisting apparently of smaller fragments of a similar nature, though much obscured by greenish alteration products and iron-ores. The quartz and epidote often tend to form in patches and irregular veins.

'7542. Merkland Burn. Similar to the preceding, but consisting of larger fragments, which are mainly andesitic, and showing very little matrix. These rocks do not resemble the matrix of the conglomerate as seen in 9393B ; but suggest rather rocks of pyroclastic origin, such as tuffs or agglomerates.'

While these rocks certainly do not resemble the conglomerate from the Sannox Burn (9393B), they are closely similar to a normal andesitic conglomerate or breccia from the Allt an Bhrighide, Glen Shurig (24369), a locality about 2 miles distant from the Merkland Burn.

Epidotization and silicification seem to have been the main processes of alteration concerned. A comparison with the alteration effected by 'pneumatolysis' around the ring structures of south-eastern Mull, which has chiefly affected Tertiary igneous rocks, especially the basaltic lavas, may be instituted. In the latter, strings, veins, and amygdales containing epidote and albite, have been developed, and olivine has been destroyed.[1] In Arran the alteration has chiefly affected arenaceous rocks, in which epidote and quartz, but not albite so far as known, have been developed. The original red and purplish tints of the rocks have been changed to greyish and greenish colours ; and at the same time the rocks have been greatly indurated, and their structural features partially obliterated, as has also been the case in Mull. The cause of this alteration was undoubtedly gaseous and liquid emanations from the neighbouring igneous centres, as Mr. Gunn, with his usual acuteness, had suggested (p. 35). At the head of the Merkland Burn, where the altered area is a mile from the granite margin, it may be surmised that a projecting tongue of granite occurs at no great distance beneath the surface. G.W.T.

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[1] *Loc. cit.*

Contemporaneous Igneous Rocks of Lower Old Red Sandstone Age

In the Lower Old Red Series of Arran, on the west side of the island, is an interbedded volcanic series. It occurs near Auchencar as a band of lava, and may be traced eastward for about 2½ miles as far as to the north-west side of Garbh Thorr, near Monyquil. Everywhere it dips steeply to the south and underlies the main mass of the conglomerates, while the strata below it consist principally of sandstones. Where this lava crops out at the surface it is largely amygdaloidal and apparently of a basic character, though the lower portion of it is in places more compact, and seems to be more basic than the rest. The best section of it occurs in the Auchencar Burn, about 70 yards east of the moor fence, where a thickness of from 50 to 60 feet is exposed. Here the rock is amygdaloidal above and compact below. As the band is nearly vertical it occupies but a narrow strip of ground, and, besides, it is a good deal concealed by drift. Still, traces of it may be found in several places to the eastward, and undoubted outcrops of it occur to the north of a conglomerate hill called Bainorlach, and also to the north-west of Garbh Thorr, where the band appears to be thicker than in the Auchencar Burn.

In the conglomerates above this volcanic zone, pebbles of an andesitic rock, presumably derived from the lava, are common. It seems probable that the volcanic series was largely denuded before and during the formation of these conglomerates, which contain these basic igneous pebbles in various parts of the island where no other traces of the former presence of these contemporaneous rocks exist. W.G.

The available slices exhibit two types of rock in this volcanic zone : olivine-andesites of basaltoid habit, and hornblende-andesites of trachytoid habit, of which the latter appears to be the more abundant. In his description Mr. Kynaston[2] doubtfully referred some of these rocks to olivine-basalt and basalt, but the minerals he described as pseudomorphic after olivine may in some cases be resorbed hornblendes. Pebbles from the conglomerates that overlie the lavas, and from other horizons, most often consist of hornblende-andesite.

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[1] 'Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1924, p. 94.

[2] 'Geology of North Arran, etc.', *Mem. Geol. Surv.*, 1903, pp. 171–173.

A slice of a lava from the Auchencar Burn (9388) shows numerous pseudomorphs in colourless serpentine after olivine, and a few highly-calcified microphenocrysts probably of a pyroxene, in a groundmass consisting mainly of plagioclase felspar (andesine and oligoclase-andesine), with magnetite and small flakes of biotite. This rock is on the borderline between andesite and basalt, and resembles the olivine-andesites that have been described from Lower Old Red Sandstone volcanic horizons elsewhere in Scotland.[1] Other two rocks of approximately the same characters occur N.W. of Garbh Thorr, near Monyquil, in the same area (9389–90). The olivine (?) pseudomorphs are black with separated magnetite, and pyroxene microphenocrysts are definitely recognizable as such.

The hornblende-andesites occur as pebbles in the Lower Old Red Sandstone conglomerates. Mr. Kynaston has described a typical example as follows :—

> '9391. Scar, east of Creag Mhòr, Auchencar. Pebble in Lower Old Red conglomerate. A reddish purple lava with irregular amygdales of calcite, and showing small porphyritic felspars. This is evidently a more acid type of rock than any of the preceding. The microscope shows numerous idiomorphic crystals and crystal-groups of brownish hornblende, for the most part now almost entirely replaced by pseudomorphs of iron-oxide. Sometimes the inner portion of the crystal retains some of the original brown colour, but there is invariably a deep opaque border of iron-oxide. Pleochroism is scarcely noticeable. The characteristic cleavages of the original hornblende may be seen in one or two cases. The felspar phenocrysts are fairly numerous. They are evidently mainly plagioclase, probably an acid variety, though some individuals only show the Carlsbad twinning. Apatite is accessory, and of a brownish tint. The matrix consists mainly of small felspar microlites (trachytic type), though a good deal obscured by small flecks of iron-ore. *Hornblende-Andesite.*'

Other very similar rocks occur as pebbles in the Lower Old Red Sandstone conglomerates of the Sannox Burn (9392, 9393A and B). A recently collected specimen of the Lower Old Red Sandstone conglomerate from the Allt an Bhrighide, Glen Shurig, Brodick (24309) shows numerous large pebbles of hornblende-andesite similar to that described above, but with beautifully developed trachytic texture in the groundmass, in a matrix consisting almost entirely of small chips, crystals, and comminuted debris from the same rock.

Intrusive Igneous Rocks of (?) Lower Old Red Sandstone Age

In Glen Rosa, about three-quarters of a mile west of the hamlet, is an intrusive sill in the Lower Old Red Sandstone. It crops out in the southern bank of the stream, and may be traced up the hillside to the southward and over the moor for nearly a mile. Two prominent knolls formed by it are called Torr Breac and Torr Dubh, and at these places the sill is about 300 feet in width. The rock is very massive, fine grained, grey or pinkish in colour, and contains in places veins of epidote. It is a peculiar rock, and seems of an intermediate rather than basic composition. It appears always to contain a pale-coloured augite, and is a salite-diabase. Three slices of this intrusion are contained in the Survey collection (7444, 7519–20). Mr. Kynaston [1] described the rock as consisting

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[1] G. W. Tyrrell, 'A Petrographical Sketch of the Carrick Hills,' *Trans. Geol. Soc. Glasgow*, vol. xv., part i., 1914, pp. 64–83.

> 'essentially of more or less lath-shaped felspars, grains and aggregates of pale augite, patches of chlorite, and some secondary quartz. Apatite and iron-ores are accessory. Grains of epidote are sometimes seen, and the rock is occasionally traversed by narrow veins of epidote and calcite.'

Upper Old Red Sandstone

The rocks of this division of the Old Red Sandstone have been much studied in the island of Arran, where they occupy the shore from the old March of Achag (not Achab) Farm, north of Corrie, to the Fallen Rocks at Corloch, a distance of 3 miles. They were supposed to be typical of the whole formation of the island, but, as will be seen from the sequel, they represent only the upper part of the formation, while the Lower Old Red division is only seen in the interior on this side of the island. The equivalents of these beds in Great Cumbrae and in Bute were, while the survey of those islands was in progress, classed with the Lower Carboniferous rocks, with which they are in general perfectly conformable in the matter of dip and strike. In all three localities there are alternations of red sandstones, often false-bedded, with brecciated conglomerates, made up largely of fragments of quartz and schist derived from the denudation of the metamorphic rocks. Mingled with these, which are often more or less angular, are well-rounded pebbles or blocks of quartzite derived from the conglomerates of the Lower Old Red division. Bands of shale, when they occur, are thin, and they form but an insignificant portion of the whole. As may be gathered from the name of the division the rocks are generally of a red colour.

No organic remains have been found in these rocks, save doubtful fragments of plants on the shore about a quarter of a mile south of Farchan Mòr.

On the north side of North Glen Sannox there are two distinct sets of beds, separated by a contemporaneous volcanic series, which probably belong to the upper division of the Old Red formation.

Above the shepherd's house we find, along the hillside, a purplish-red felspathic sandstone which is pebbly in places. The pebbles are generally small, and are of coarse, reddish quartzite and white quartz, which are mingled together. Some thin bands of purplish and red mudstone, like the thick masses which occur lower down in the formation, are occasionally seen. The pebbles which occur in the sandstone are well rounded, especially those of quartzite. The dip of these rocks is clearly to the east-north-east, at angles of from

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[1] 'Geology of North Arran, etc.', *Mem. Geol. Surv.*, 1903, p. 173.

20° to 30°. These beds undoubtedly are the upper portion of the Lower Old Red Sandstone.

At the top of the slope where these beds are found a line of crags may be observed which consist of a very different type of rock, a whitish conglomerate in a nearly horizontal position, and with every appearance of being unconformable to the beds first described. The pebbles in this conglomerate are mainly of white quartz not well rounded, though a few of the well-rounded quartzite pebbles common in the lower division also occur. The numerous quartz pebbles give the rock a decidedly grey colour when seen from a distance, though the matrix is often somewhat tinged with red. Farther west, beyond the first large fault, there are many rounded quartz pebbles and some of schist in the basement beds. The rocks in these crags must be considered as the lowest portion of the Upper Old Red division. They have a gentle dip to the northward and pass under a succession of massive, whitish conglomerates of like character, which alternate with reddish, flaggy sandstones. The whole forms a fine set of parallel escarpments much broken by faults. The dip gradually increases till it reaches 25° or 30° in the highest beds of the series, a set of whitish and somewhat flaggy sandstones which are occasionally pebbly and which underlie the contemporaneous igneous rocks. The beds as above described have a probable thickness of about 800 feet below the lavas. The latter are purplish-red rocks, often amygdaloidal and decomposed, which are elsewhere described (*see* p. 42). They are much faulted ; their thickness is probably not more than 100 feet at the most, and they appear to thin away rapidly to the southward. Above them comes a series of red, flaggy sandstones which are surmounted by the ordinary red conglomerates and sandstones partly exposed along the adjacent coast, the highest bed of which has furnished the material for the Fallen Rocks. To the south-east of the Rocks it is principally conglomerate we find on the shore for a distance of half a mile, when, after passing a fault ranging north-east, we come upon the flaggy sandstones which overlie the volcanic series. These occupy the shore for some 600 yards farther. They dip N.E. and N.N.E. at comparatively low angles, 15° on average, and at the south end are faulted against a coarse conglomerate, which occupies the shore for 200 yards, and is then cut off by a fault ranging E.N.E., which brings up much lower beds. From this point, which is 700 yards from North Sannox Burn, the section is very complicated and could not be described accurately without much detail. There are numerous faults and in one place irregular bands of impure cornstone, perhaps on the same horizon as one seen at Farchan Mòr. There is no trace of the volcanic series, and nearer to North Sannox there is strong evidence for an unconformity, where in more than one place dull red sandstone abuts in a peculiar way against conglomerate. Perhaps this may be the reason for the absence of the lavas. As we approach the burn the dip tends more and more towards the east, and on the south of the stream it becomes south of east, and we have passed over the anticlinal line so called. The sandstones and conglomerates that lie immediately south of the burn dip about E.S.E. at angles of 30° to 40°. They strongly resemble the beds which are known to occur below the lavas, and it is very probable they are a part of that series. Above them there appears to be an unconformity of the same kind as that occurring north of the burn. The rocks which succeed are a series of flaggy red sandstone with occasional pebbly bands, and these continue to the cross-wall, where comes on the thick conglomerate which extends a long way on the shore and which forms the fine crag called the Blue Rock. At the south end of the shore-section, nearly a quarter of a mile from the South Sannox Burn, is an interesting section. A sharp line on the foreshore running N.N.W., which appears to be a joint and not a fault, divides sandstone from conglomerate for the greater part of its length, but near low-water mark sandstone is found on both sides of this line, beyond the point where the conglomerate is seen to overlap beds of sandstone. Near high-water mark, also, conglomerate occurs east of the line, wrapping round beds of sandstone. It is clear in this case there is a local unconformity. Somewhat similar cases occur south of Farchan Mòr, one of which is near the Rocking Stone. The coarse conglomerate bed on which stands this stone overlaps beds of soft, shaly, red sandstone which lie below. A large fault which runs nearly parallel to the coast truncates this conglomerate near high-water mark, perhaps a continuation of the fault which passes on the west of the Blue Rock; and some distance southward there are several smaller faults. Near these some curious hardened markings project from the surface of the sandstone; some appear vertical like finger ends, and others resemble worm castings which are arranged into various patterns. The rocks to the southward are mostly red sandstones, sometimes false-bedded, which dip south-east at angles from 20° to 30°. There are some beds of conglomerate, one of which forms the highest part of the formation, about a quarter of a mile north of the Corrie Schoolhouse. These higher beds are shown in the section of the Carboniferous rocks (Fig. 1, p. 45).

To the west of Corrie the ground occupied by the Old Red Sandstone is much faulted, and also obscured by glacial deposits, and the division between the upper and the lower parts of the formation is very uncertain. Most of the writers on Arran describe a narrow band of schist or slate along the eastern border of the granite for a distance of about 3 miles southward from Glen Sannox, but Old Red Sandstone certainly is the rock which occupies this position excepting for a length of half a mile to the east of Cioch na h-Oighe, where a band of altered schist occurs next to the granite. It is mainly the lower division of the Old Red Sandstone that is in contact with the granite along this line, and it is doubtful if the upper division and the granite ever come together. The width, however, occupied by the whole formation as it is exposed at the surface is narrowed to 500 yards at the Locherim Burn, and is not more than 400 yards south of the White Water.

The lower boundary of the upper division to the south of Corrie is but an arbitrary line, as the dip and strike of both divisions are the same. It has been drawn, however, through the Brodick woods and up Glen Shurig, so as to include in the upper division rocks which could not be referred to the lower division. South of Glen (Gleann) Dubh, where nearly all the Old Red rocks are much altered, the more felspathic rocks of the Lower Old Red become grey in colour, while the more quartzose rocks of the upper division are turned white, and this difference in colour assists one considerably in deciding on the boundary between them. Some of the rocks of the Upper Old Red are converted into quartzite.

In the Clauchan Glen, to the south-west of Beinn Bhreac, there is a thick series of white sandstones and conglomerates which apparently occupy the position of the Upper Old Red rocks, though they do not much resemble them in character, and certainly not in colour. The white colour may be due, however, to the same cause which has so highly affected the Lower Old Red Sandstone of this district, viz., the intrusion of the granophyre and other rocks of Beinn Bhreac.

On the western side of the island the beds above the genuine Lower Old Red Sandstone are very variable. On the shore and in the old sea-cliffs north of Auchagallon they are mainly conglomerates with some pebbly sandstones. In the Machrie Burn the proportion of conglomerate to sandstone is not so great, and in the Machrie Water there is a great thickness of soft red sandstone with few or no pebbles in what has been taken as the lower part of the upper division. W.G.

In the area to the south of the Central Ring structure, the Upper Old Red Sandstone consists largely of white conglomerates and sandstones, the latter being well exposed in the Clauchan Burn. To the south these rocks are bounded by the Carboniferous formations, but the junction is uncertain and obscure. The rocks of this area do not at first sight much resemble the typical Upper Old Red Sandstone of other parts of the island, as they are in the main white and not red. The change of colour may be due to alteration ; not, however, effected by the intrusion of igneous rocks actually seen here, but by the same cause which has so metamorphosed the Lower Old Red Sandstone farther north—the intrusion of the large mass of granite and granophyre which forms part of the Central Ring area. There are some indications that even as far south as the Clauchan Burn, the igneous rocks may not be far below the present surface, a view which is supported by the fact that the plane of junction between the igneous mass and the altered sedimentary rocks appears to dip at a low angle to the southward.

In the area north-east of Cnoc a' Chapuill these beds strike north-east with a steep dip to the south-east, and often they are vertical. They consist largely of white quartzose sandstones, very fine grained and hard, with bands of pink and white quartz pebbles. In several places the rock is really a quartzite. Other outcrops in the peat are of white pebbly sandstone, and occasionally there is some sandstone of a red colour. In the burn east-north-east of Cnoc a' Chapuill there is a band of rather hard red shale several yards in thickness, which strikes nearly east and west. Below this comes fine quartzose sandstone, and then appears a band of white quartz-conglomerate, which has a steep dip northward and must be inverted. To the north-west of Cnoc a' Chapuill there are few outcrops until the upper part of a small tributary of the Clauchan Burn is reached. Here, for a long distance, there is a continuous section in rather flaggy and well-bedded yellowish quartzose sandstones, which dip uniformly between 25° and 30° in a direction between S.W. and S.S.W. These beds apparently form the lower part of the Upper Old Red Sandstone, and immediately overlie the much-altered rocks of the lower division previously described. The south-westerly dip prevails in the section of these rocks exposed in the main stream of the Clauchan Burn, and on the hillsides to the south, and the amount generally varies between 20° and 30°. The rock is almost everywhere of a white colour; is often fine grained, and is occasionally pebbly. Sometimes, as is the case a mile due west of the Ordnance Station on Cnoc a' Chapuill, the white sandstone has a carious appearance on the weathered surface.

Lower down the main stream of the glen from the base of the subdivision there are exposed fine, evenly-bedded sandstones, mostly of a white colour, and generally hard. Farther down, the rock contains pebbles. The section is not continuous, but there are successive exposures of nearly white, hard, blocky, fine-grained sandstones dipping S.W. at 20°. West of the intrusive mass of quartz-porphyry, fine, hard, quartzose sandstone, which is nearly white, reposes on slaty, red, micaceous sandstone, which has all the usual characters of the Upper Old Red Sandstone. Lower down yellowish sandstone, apparently false-bedded, dips W.S.W. at 10° to 15°; and still lower, and just above a rocky gorge, some ripple-marked sandstone dips as low as 5° to 10°. The gorge is cut in hard and thick white shattered sandstone, and a little below this is placed the fault—for fault there must be—which brings down against these beds the Triassic rocks that are well exposed lower down the glen. This fault, which has a course nearly north and south, accounts for the ending-off of the Clauchan Limestone (Lower Carboniferous) at its west end on the south side of the glen.

W.G. (MS.)

Contemporaneous Igneous Rocks of Upper Old Red Sandstone Age

The Upper Old Red Sandstone of Arran contains an interstratified and contemporaneous set of lavas on the north side of North Glen Sannox. The area in which these volcanic intercalations occur is much faulted, but the position of the interbedded igneous rocks is quite clear. The Old Red Sandstone of this part of the island consists of three distinct members, the lowest of which is made up of coarse, well-rounded conglomerates, alternating with felspathic sandstones and purplish mudstones. These are the undoubted Lower Old Red rocks. Above this set comes a middle series of light-coloured or reddish conglomerates and sandstones, the pebbles in which are mostly of quartz. This series is apparently unconformable on the lower. Lastly comes an upper series of red sandstones and conglomerates which occupy nearly the whole of the coast section in which the Old Red Sandstone appears, and it is this series which has generally been supposed to be typical of the whole of the Old Red Sandstone of the island. The volcanic series is intercalated between the middle and the upper divisions above described, and it crops out in many places high above the hillside between the shepherd's house at North Sannox and Laggantuin, but is very discontinuous from being much faulted. It consists of dull-red or purplish lavas, in places soft, and often much decomposed. The general character of the rock is basic, but a specimen from near the Fallen Rocks which [Sir] J. J. H. Teall examined was found to be too much altered for precise determination, though it was probably a basalt originally. No trace of these rocks is found along the coast, nor in any other part of the island of Arran. W.G.

The three slices of Upper Old Red Sandstone lavas that are available (6370, 9394, near Fallen Rocks; 9395, hillside above Laggantuin) show that these rocks are decidedly more basic than those of the Lower Old Red Sandstone; and at the same time their characters exhibit an approach to well-known Carboniferous types. In spite of considerable alteration there may be recognized in the slides numerous, idiomorphic, serpentinized microphenocrysts of olivine, in a highly-felspathic groundmass consisting of oligoclase, magnetite, and decomposition products. These rocks may be regarded as intermediate between olivine-andesites, and basalts of mugearitic, Jedburgh, and Dalmeny types. G.W.T.

CHAPTER VI

THE CARBONIFEROUS ROCKS

INTRODUCTION

ONE of the most remarkable results of the geological survey of Arran is the restricted area now assigned to the Carboniferous rocks which were formerly supposed to cover a large part of the island, and it may be as well before entering into details about these strata to remove certain misapprehensions as to their position, distribution, and thickness. The Carboniferous series, it has long been known, is typically developed and best studied along the eastern coast, where it forms a narrow strip which stretches for about 3 miles between the Cock and the Fallen Rocks. Its thickness here has been much exaggerated because no account has been taken of numerous faults by which the strata are repeated. A narrow band of the formation, 200 yards in width, also occurs on the north shore near the mouth of the burn east of North Newton. This strip lies between two large faults. Along the shore at Corrie, Carboniferous strata stretch for two-thirds of a mile, with a dip of 20° to 25°, until they are overlapped by the New Red Sandstone 250 yards south of the Corrie Hotel. The total thickness of the Carboniferous rocks on this shore may be as much as 1200 or 1500 feet, inclusive, as at Laggan, of a volcanic group 300 or 400 feet thick. Several thin red limestones occur near the upper part of the series, but the most prominent members are the volcanic group, the thick Corrie limestone, and the white sandstones immediately above that bed. It is by these well-marked bands that the series can be followed inland and recognized among the numerous faults, some of which bring up the Old Red Sandstone and confine the Carboniferous rocks to a comparatively narrow belt. One of these north-north-west dislocations, with a throw greater than the total thickness of the series, shifts the base of the volcanic group into the burn north of Maol Donn, and another large fault running along the west side of that hill has moved the main body of the Carboniferous rocks southward again for more than a mile. The strata reappear in the Merkland Burn, whence they can be traced to the south-west through the wood, and behind Brodick Castle, in a steeply-dipping band altogether not more than 200 to 300 yards in width. Though they disappear under the Brodick alluvium, some of the sandstones and shales are visible in the Rosa Burn about the bridge, and the thick white sandstones are a conspicuous feature about the manse and church. Behind the churchyard the thick Corrie limestone was formerly worked. A little farther west a large fault throws the rocks up to the hillside where the thick white sandstone forms a marked feature, and the limestone immediately below has been worked. The Carboniferous band here is 200 yards wide only, and dips steeply to the south-east ; the New

Red rocks, extremely false-bedded as usual, forming the high bank above. The volcanic group crops out here and there at the base,

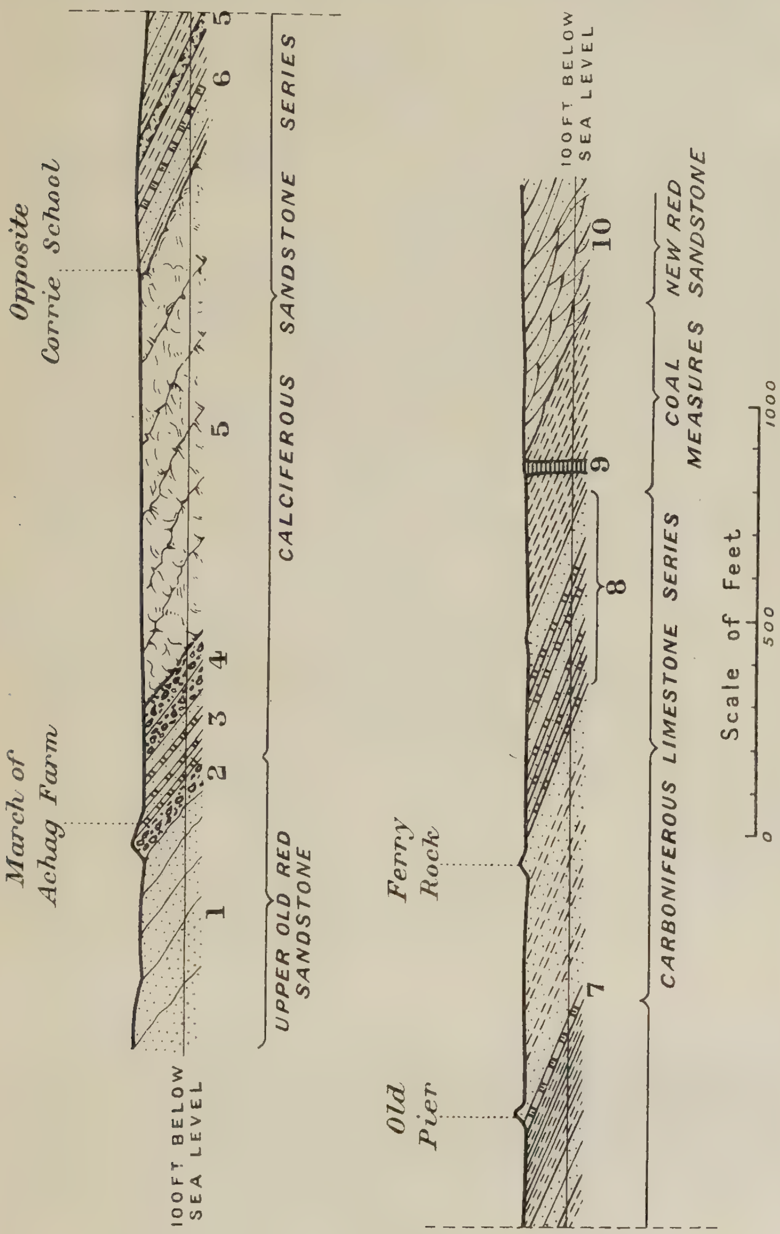

FIG. 1.—*Section along shore opposite Corrie.*

1. *Sandstones*; 2. *Conglomerate*; 3. *Cornstones*; 4. *Tuffs*; 5. *Lavas*; 6. *Limestone* (*red*); 7. *Limestone* ('*Corrie*'); 8. *Upper Limestones*; 9. *Basalt*; 10. *Red Sandstone.*

and the whole series can be followed south-west to Windmill Hill, where it becomes entangled among intrusive masses of various kinds, which, along with faults, have displaced the rocks so that they do not occur again till the south side of Glen Dubh is reached. This locality is more than a mile south-east of Windmill Hill, where they were lost sight of.

From Glen Dubh the Carboniferous formation may be traced in a number of detached outcrops separated by faults southwards by Benlister Glen, and Cnoc a' Chapuill, to near the Clauchan Glen, being recognizable by the presence of the volcanic group, after the Corrie limestone has been overlapped by the New Red Sandstone. There is no trace of these rocks on the west coast, the New Red Sandstone reposing directly on the Old Red Sandstone without the interposition of any Carboniferous strata. W.G.

The Carboniferous formation thus undergoes attenuation from north-east to south-west. The greatest thickness is in the north-east at Laggan ; south of the Central Ring Complex the strata become very thin ; whilst on the coast north of Machrie Bay the Carboniferous was probably not deposited at all.

The Carboniferous formation in Arran includes representatives of the Calciferous Sandstone with their intercalated lavas, the Carboniferous Limestone Series, and the Coal Measures with an indeterminate amount of Millstone Grit, and a contemporaneous volcanic series. According to Gunn's estimate (p. 48), the total thickness is only between 1300 feet and 1400 feet, except at Laggan, where the thickness may be 2650 feet (Gunn, 'Geology of North Arran, etc.', *Mem. Geol. Surv.*, 1903, p. 46) ; and, therefore, the Arran succession is attenuated or telescoped as compared with that of the Scottish mainland. The prevalent pink and red colours of the strata are regarded by Mr. E. B. Bailey as due to oxidation during New Red Sandstone times, and not to the downward percolation of iron-bearing solutions from that formation.[1]

The Carboniferous outcrops lie almost entirely within the semicircular zone of adjustment-faulting consequent upon the development of the two igneous centres of the northern granite and the Central Ring Complex ; and therefore comprise narrow faulted strips placed in echelon around the eastern and southern margins of the igneous masses. The dip is usually steep, and varies from due east to due south, in harmony with the view that the attitude of the formation is consequent upon the doming of the igneous centres.

G.W.T.

The Calciferous Sandstone Series

The Calciferous Sandstone sediments and lavas occur in practically all the above-mentioned Carboniferous outcrops. The only outcrop from which they are believed to be absent is that occurring at the head of the southern branch of the Sliddery Water (p. 70). The sedimentary rocks consist of variously-coloured sandstones, red, purple, and white in colour, often calcareous, pebbly, or conglomeratic ; red shales ; and grey to pink cementstones and cornstones.[2]

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[1] *Geol. Mag.*, vol. lxiii., 1926, pp. 276–281.

[2] It should be noted that Mr. E. B. Bailey considers that the cornstones frequently found towards the base of the Calciferous Sandstone Series in Arran should be relegated to the Upper Old Red Sandstone (*Geol. Mag.*, vol. lxiii., 1926, p. 277).

Intercalated with the sediments there are the products of a considerable volcanic episode, which has given rise to tuffs, agglomerates, and basaltic lavas of types familiar in the Lower Carboniferous of Scotland (p. 57).

The principal sections will be described in order from north to south.

G.W.T.

DETAILS OF SECTIONS

The remarkable junction of schists, and cornstones of the Calciferous Sandstone Series, on the shore at North Newton is one of the classic sections of Arran, and has often been described. It seems to have first been noticed by the celebrated James Hutton in the year 1785, and his description of it appears first in the third volume (p. 235) of his *Theory of the Earth*, which remained in MS. till edited by Sir Archibald Geikie in 1899. It may be worth while to quote a part of this description :—' Lochranza, at the north end of the island, is properly within the alpine schistus ; but, in tracing the shore, upon the east side of the loch or bay, we come to the extremity of this schistus district. Here the first thing that occurs is the immediate junction of the inclined strata of schistus and the other strata, which here appear to be a composition of sandstone and limestone ; these strata are equally inclined with the schistus, but in the opposite direction. Those two different kinds of stratified bodies rise to meet each other ; they are somewhat confused at the immediate junction ; but some of the sandstone or calcareous strata overlap the ends of the alpine schistus.' Hutton made a drawing of the junction, which has been lost. Its place is supplied in the volume by a sketch from Sir A. Geikie.

The exact locality of the section is on the foreshore about one-third of a mile north-east of the most northerly farm in North Newton, on the eastern side of a stile and wire fence. The rocks consist of beds of red and yellowish sandstone with lenticular calcareous bands, and distinct beds of white cornstone. They stretch along the shore for nearly 400 yards, and project nearly half-way across the raised beach. At the south end they dip N.N.W. at 30°, and at the north end W.N.W. at 25°, so that the strike describes a curve of 45°. The schists on which they rest unconformably dip S.S.E. at 40°.

Sections on the North-East Coast.—The Laggan section of the Carboniferous stretches along the north-eastern shore of Arran, from the Fallen Rocks, near Corloch, for a distance of 3¼ miles to within 600 yards of the Cock of Arran. The shepherd's house at Laggan is 2 miles from the Fallen Rocks, while Millstone Point is a like distance from the northern end of the strip, the length of which, however, is only 3⅛ miles, as the coast-line is not straight. The width of the strip varies, but in general is not more than a quarter of a mile ; it widens to half a mile at Cock Farm, but in two places south of Millstone Point it does not exceed 200 yards.

The dip is everywhere high, and nearly in the same direction ; lowest at the north end, where it is about 30°, but for the greater part of the distance it is 40° or 50°, and even 60° in places. This high dip suggests an enormous thickness of beds, but it must be remembered that the general dip is in a direction to the east of north, while the trend of the coast is about 40° north of west, and is only 30 or 40 degrees removed from the general strike of the beds. In fact, there are parts of the coast-line where its direction coincides very nearly with the strike for some distance. In addition to this consideration it must be borne in mind that there are several large faults, especially in the lower part of the section, which repeat many hundred feet of the strata. Still, there is no doubt that we have here a much greater development of Carboniferous rocks than we have at Corrie; probably the thickness of the whole is twice as great, and if we confine our attention to the sedimentary beds alone the disproportion is still greater. The increased thickness is not confined to one part of the section. All the limestones are thicker than they are at Corrie, and they are more in number—there are coals which are absent at Corrie, and naturally there is a much greater development of sandstone and shale. The following is a comparative estimate of the thicknesses of the various subdivisions in the two sections:—

	CORRIE.	LAGGAN.
Coal Measures	150 feet.	250 feet.
Limestone Series	425 ,,	750 ,,
Calciferous Sandstone Series above and	75 ,,	575 ,,
below traps	275 ,,	700 ,,
	925 ,,	2275 ,,
Add thickness of Volcanic Series ..	450 ,,	375 ,,
	1375 ,,	2650 ,,

The greatest difference is in the thickness of that part of the Calciferous Sandstone Series below the volcanic zone, which is less than 300 feet at Corrie contrasted with 700 feet in the Laggan section. It has been suggested that the trap at Corrie is a great dyke which conceals a very large fault, and that this accounts for the differences between the two sections; but the fault at Corrie, if it existed, would not explain why we have increased thicknesses at Laggan in all the sedimentary beds. Besides, we know that the thinning of the Carboniferous beds at Corrie as compared with those at Laggan is continued southward, so that in the neighbourhood of Brodick Castle and in Glen Shurig the total thickness is about 600 feet.

Some 300 yards south of the Fallen Rocks the cornstone base of the Carboniferous rocks occurs in two places separated by a small fault. The cornstone is pebbly and adheres to the conglomerate below in an unconformable manner, like that described in the junction north of Corrie. This is separated by a considerable north-trending fault with a downthrow eastward from the main mass of the Carboniferous section which commences on the north side of the Fallen Rocks. The beds here have a fairly steady dip of 30° to 40° to the northward, often inclining east of north sometimes as much as 15° or 20°. There are two cornstones of the usual light-coloured concretionary character, which are sometimes pebbly, and irregular in thickness. They are separated by a few feet of sandstone. There succeed to the northward a series of red clays with some lenticular calcareous bands, and red sandstone with quartz pebbles. These are bounded on the north by a fault which crosses the foreshore in an easterly direction, and throws down on the north an alternating series of grey shales, thin sandstones, and calcareous bands. Among these Mr. James Thomson[1] discovered a brecciated or tuffaceous rock from which he obtained remains of plants and fish. At this locality, about 300 yards north of the Fallen Rocks, Mr. Tait, the collector for the Survey, obtained the following species:—

Cordaites sp.
Fern rachis
Sphenopteris sp.
Palæoniscid scales (indet.)
Rhizodus hibberti (*Ag.*)
Rhizodus ornatus *Traq.*
Strepsodus striatulus *Traq.*
Fish-head plate
Various bones and plates (indet.).

Above these grey beds there come about 150 feet of an alternating set of white sandstones and red clays or shales, the clays containing several small lenticular cornstone bands, the uppermost of which are fairly good continuous limestones, 1 to 2 feet thick, of the same character as the basal cornstones. These beds are surmounted by thick-bedded white sandstone, which continues for but a short distance, and then the section is lost for several hundred yards. Some 200 yards, however, beyond the most northerly Laggantuin Burn, white sandstones, with a northerly dip of 60°, appear in the old sea-cliff, and these strongly resemble the pebbly sandstones of Millstone Point, a long way to the northward. In fact, there is not much doubt this is their position in the series. To the west of these is a large fault with a downthrow east of several hundred feet. On the west side of this the upper beds of the Old Red Sandstone, and all the lowest beds of the Carboniferous, including the cornstones, are exposed in a precipitous hill. The fault runs northward along the east side of this hill, but on reaching the shore it, or a branch of it, runs along the foreshore in a north-west direction for 250 yards and then passes out to sea. On the inner side of this fault, along the foreshore, we again come upon the Millstone Point grits, but we do not find a continuous section up to the base of the volcanic series, for the beds immediately underlying that series are cut out by two parallel faults along the strike. Nearly a mile from the Fallen Rocks there is exposed on the shore a good section of the volcanic series, consisting of alternations of basic lavas with coarse and fine tuffs, the whole amounting in thickness to between 350 and 400 feet. These, which are elsewhere described in some detail (*see* latter part of this chapter), occupy the shore for a distance of over 200 yards, dipping steeply northward at 50° to 60°, but they do not appear in the old sea-cliff to the west, being cut off on that side by a large fault which runs in a northerly direction across the foreshore. This brings up again the beds below the trap, which are seen at intervals on the shore, the highest beds being grey cementstones like those underlying the trap near Laggan. Above these comes a portion of the volcanic series again, which is bounded on the west by another large fault bringing up against it sandstones and shales of a much lower horizon.

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[1] 'On the Stratified Rocks of the Shore-line from Clachland Point to the Cock of Arran,' *Trans. Geol. Soc. Glasgow*, vol. xi., part i., 1898, pp. 12–30.

To the northward come white sandstones, some of which are coarse, alternating with red shale and clay bands, and in one place some cementstones and grey beds. These continue as far as the bay, south of Millstone Point, where there is a gap in the section. The rocks, however, are almost continuously exposed on the hillside to the south of this bay, and there can be no doubt whatever about the general order of succession. The dip is almost everywhere to the east of north, and between 50° and 60°. On the north side of the little stream called the Garbh Allt, white pebbly grits are well exposed at Millstone Point. In places the quartz pebbles in the rock are large, some being as much as 4 inches in length. We cross a small and unimportant fault, and pass upward into alternations of white sandstone and dark shale with traces of coal. These are succeeded by grey sandstones and blue and grey cement stones alternating with thin tuff bands, and in the upper part with two thin beds of lava. This is the spot, some 750 yards south-east of Laggan cottage, where Wünsch discovered trees and plant-remains, imbedded in trappean ash,[1] in the year 1865. It is interesting to note that these plant-remains, which are accompanied in this locality by thin coal-seams, occur on the same geological horizon as the coal which was formerly worked at Ambrisbeg, and at Ascog in the island of Bute, but in no other place within this Sheet is a coal known to occur at the base of the volcanic series.

The following set of fossils was obtained 750 yards south-east of Laggan cottage :

Lepidophloios wünschianus *Will.*
,, sp.
Rhacopteris sp.
Zeilleria moravica (*E.H.*)
Diplothmema patentissimum (*E.H.*)
Sphenopteris sp.
Stigmaria.
Allorisma sulcata *Flem.*
Edmondia pentonensis *Hind*
Sedgwickia gigantea *M'Coy.*

These beds, which dip at a somewhat smaller angle, from 35° to 40°, are succeeded by the principal mass of trap, elsewhere described (*see* latter part of this chapter), and above this there is a thin cementstone series again, alternating bands of grey beds, shales, cornstones, and sandstones with some tuffaceous bands. A thick series of white blocky sandstones, alternating with thin bands of red shale, forms marked features west of the shepherd's house, and these continue till we reach the Corrie or Hurlet limestone, nearly 250 yards north-west of the house.

From a place 100 yards south-east of the cottage *Sphenopteridium crassum* (L. and H.) and another species were obtained, and a few yards north of the cottage *Sph. crassum ?* and a species of *Stigmaria.*

Lavas and tuffs of the Calciferous Sandstone Series occur three times between Corloch and the shepherd's house at Laggan. These rocks are all of basaltic composition (p. 57). The most northerly exposure occupies the shore for nearly a quarter of a mile, its southern boundary being nearly half a mile from Laggan. The greater portion of the outcrop consists of massive, fine-grained grey trap in which no dip is visible, but the whole series is inclined to the north at an angle between 30° and 40°, so that the total thickness must be over 300 feet. There are two fine tuff bands in the lower portion of the mass, and between these the rock is very scoriaceous, while the part below these fragmental bands is soft. Below the main mass are alternations of thin lava beds and fine shaly tuffs, in some of which Wünsch was the first to discover remains of Carboniferous plants (see *Trans. Geol. Soc. Glasgow*, vol. ii., pp. 97 and 160, 'On the Occurrence of Fossil Trees imbedded in Trappean Ash in Arran').

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[1] 'On the Occurrence of Fossil Trees imbedded in Trappean Ash in Arran,' *Trans. Geol. Soc. Glasgow,* vol. ii., part ii., 1866, p. 97.

The ordinary Calciferous sandstones and shales underlying the traps succeed to the southward, but owing to large faults we find repetitions of the volcanic series to the south of Millstone Point, where the lavas again occur, but the tuffs are much coarser than in the last section and form a large proportion of the whole series, so that here we are probably nearer the site of a volcanic vent. Nearly half a mile south of Millstone Point we find the following section on the foreshore :—

The upper portion is for the most part a slaggy and amygdaloidal lava with a little tuffaceous material, about 150 feet in thickness. This is succeeded in descending order by well-bedded greenish and red tuffs, 75 feet thick.

Lava—slaggy above and with pillowy structure below, often an irregular mass in which are several red and dark flinty bands apparently filling up cracks in the lava-flow—75 feet.

Finer tuffs with some lava—a few feet, perhaps 10.

Coarse volcanic agglomerate—75 feet.

The dip is slightly east of north at a high angle, 50° to 60°, and the total thickness must be near 400 feet.

These beds only appear on the foreshore and on the raised beach, being cut off on the west by a large fault running nearly due north with a downthrow east of some 500 feet. Some distance to the north, therefore, we find the volcanic zone again on the foreshore resting on the cementstone series. It has the same steep northerly dip, but we only see a portion of it, the lower agglomerate band about as thick as before but intercalated with some finer tuff bands, and surmounting it a portion of the grey trap bed ; and then another northerly-running fault with a large downthrow east destroys the continuity of the section.

Sections at Corrie.—It will be advisable to describe the Corrie shore-section in some detail, as it is easy to examine at low water, and is comparatively little faulted. (*See* Fig. 1). From the school-house northward there is exposed on the shore, for a distance of 350 yards, the lower volcanic series, made up mainly of massive lavas, with a thick band of coarse volcanic agglomerate at the base or northern end. To the north of this for a distance of about 35 yards are various members of the Lower Carboniferous rocks, including three limestones or cornstones, and below these projects a mass of red conglomerate which is the highest bed of the Old Red Sandstone. This is the locality called the March of Achag Farm by the older writers. The red conglomerate itself is 50 feet broad at high-water mark, but considerably less at low water, and the junction between it and the Carboniferous beds is peculiar. A joint or crush at the shore-line, running N.N.E., appears to die out towards the sea, or is overlapped by sandstone and limestone, which abut against a nearly vertical face of the conglomerate, so that this is clearly an unconformable junction. This mass of calcareous sandstone and pebbly cornstone, several feet thick, may be faulted along a north-north-east line against a few feet of overlying white sandstone which dips to the south-east at 25° to 30°. Above this lies red shale, and then comes a nodular cornstone, about 15 feet thick, with a red argillaceous matrix. A gap of a few feet separates this from the uppermost cornstone, which is a whitish, irregular, calcareous sandstone somewhat mixed with reddish sandstone, and shaly below. It may be 3 feet thick. The 15 yards of distance between this and the base of the agglomerate is almost entirely occupied by white sandstone, the beds of which dip S.E. at 25° or more, so that it is probably as much as 20 feet thick. The whole thickness of strata between the volcanic rocks and the conglomerate cannot, however, be more than 45 feet.

The volcanic agglomerate itself is 45 yards in width on the shore, and must be 50 feet thick or more. It is a very coarse rock, made up of fragments of basic trap, sometimes as much as 6 feet in length. The lower beds of the lavas are massive, bluish, and fine grained, and some of the upper are purplish in colour, but the whole is similar in composition, being a porphyritic olivine-basalt. This mass of Carboniferous lavas, which are certainly contemporary with the sedimentary rocks adjacent, is probably 300 feet in thickness.

South of the school, for a distance of 75 yards, we find sandstones and shales that overlie the lavas. The dip is in the same direction as before, but only about 20°. Most of the rocks here are of a red colour, and the shales are specially so, and some are tuffaceous. Among these occurs a thin red limestone from 1 to 2 feet in thickness.

On the shore opposite the Established Church is a projecting mass of purplish and much-veined trap 10 yards across. This is a lava bed, about 10 feet thick, and the last outflow from the old volcano in this locality. Above this is a gap of 20 yards or so, probably occupied by shales ; to which succeed thick beds of white and pinkish sandstone, which have been quarried both on the shore and up the hillside to the westward. There is probably a thick mass of red shale above this and underlying the Corrie limestone, but it is poorly exposed on the shore.

The basaltic lavas on the shore near the big boulder called Clach an Fhionn exhibit a very fine spheroidal jointing giving rise to a pseudo-pillow structure.

There are numerous sections of the Calciferous Sandstone lavas and tuffs, with the accompanying sediments, in the burns that drain the steep hillside west and south of Corrie. The beds seen near the Established Church are exposed in the burn that flows past the church, but the base of the lower volcanic mass is not seen here, for a large fault cuts off the outcrop 600 yards from the sea. This fault shifts the rocks to the southward, and both beds are exposed again in the Locherim Burns, where some intercalations of tuff occur in the lower and larger bed. Another large fault, which must have a throw of over 1000 feet, shifts the volcanic rocks again to the south, this time a distance of three-quarters of a mile to the burn called Uisge nam Fear, which is the first stream north of Maol Donn. W.G.

A good section of the Calciferous Sandstone lavas and sediments is exposed in the Church Burn. The exposures begin about three-quarters of a mile from the sea, where the quartz-conglomerate of the Old Red Sandstone, dipping steeply to the south-east, is followed by a thick series of soft, red, crumbling sandstones, intersected by four basalt dykes. There are occasional harder bands containing small pebbles of quartz and chips of shale. Between the third and fourth dykes alternations of quartz-conglomerate and sandstone are seen. The fourth dyke appears to have risen along a fault-line, which brings coarse agglomerate against the quartz-conglomerate. Only a few feet of thickness of the agglomerate is seen, and it is succeeded by a thick flow of porphyritic basalt. Then comes decomposed amygdaloidal material representing the junction between two flows, followed by a second flow with well-marked spheroidal jointing like that of the shore-section. Another band of decomposed material separates a third lava flow, also with spheroidal jointing. This is overlain by soft, green and red, sandy shales, intercalated with well-bedded tuff. Then comes 4 feet of cream, red, and grey compact limestone or cornstone, followed by more tuff. As the stream now runs nearly along the strike of the rocks, this limestone and tuff are seen in the bed of the stream until near its mouth. In one place a feet few of bright red shale succeeds the cornstone. Close to the shore a decomposed, veined, highly amygdaloidal lava appears, which is correlated with the upper lava band on the Corrie shore. This lava is overlain by mottled red and green shale, followed by red sandstone.

A very similar section is seen in the North Locherim Burn, with the exception that tuff and agglomerate here greatly predominate over lavas.

An excellent section of the Calciferous Sandstone Series is exposed in the Uisge nam Fear (Fig. 2). The rocks are first exposed a little west of the 282 feet O.D., about half a mile from the sea, and consist of coarse white and pink mottled sandstone dipping about 30° to south-east. Upstream, after a short blank interval, the lavas are seen, and their base can be well followed in the gorge west of the 341 feet O.D. The section in the gorge is as follows :—

	Ft.
Basalt lavas	—
Tuffaceous sandy shales and tuffaceous sandstones	30
Bright red shale, with green patches	1
Coarse sandy tuff	1½
Bright red shale with green spots	3
Hard white sandstone	3
Bright red sandstone.	

The section in the upper part of the gorge is rather obscure and confused owing to many small faults (*see* section, Fig. 2).

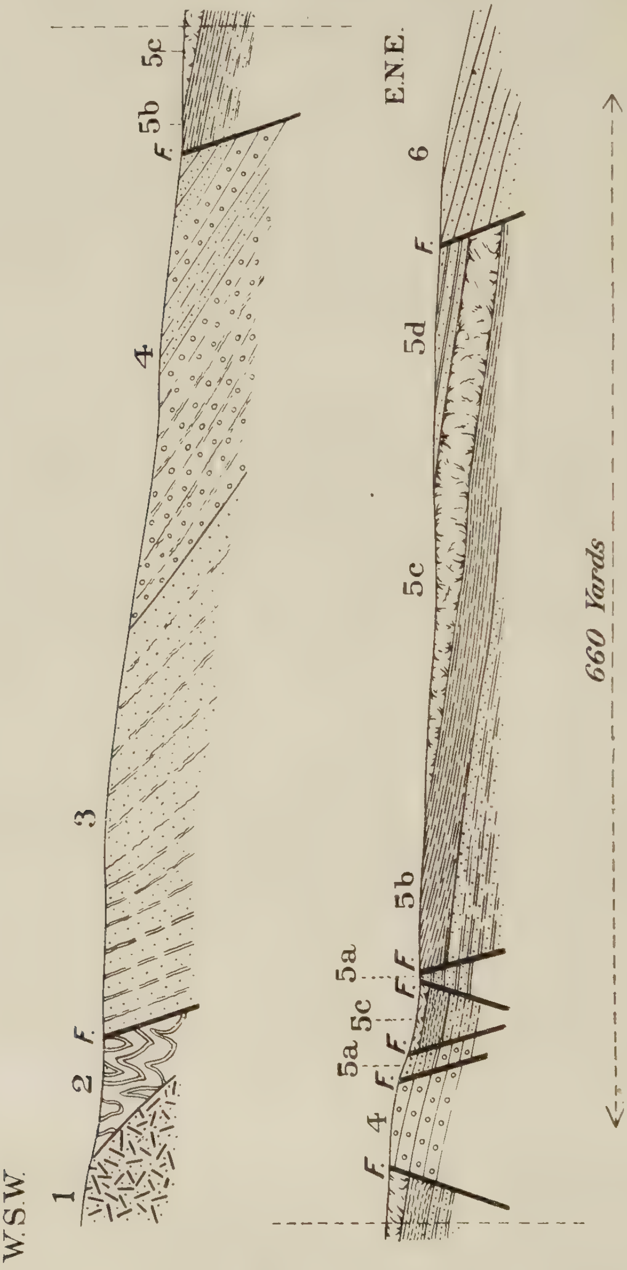

FIG. 2.—*Section along the Uisge nam Fear, half a mile south of High Corrie.*

1. *Granite*; 2. *Dalradian schists*; 3. *Lower Old Red Sandstone*; 4. *Upper Old Red Sandstone*; 5. *Calciferous Sandstone Series*; 5a. *Lower group of sandstones*; 5b. *Basaltic tuffs and red shales*; 5c. *Basalt lavas*; 5d. *Upper sandstones and marls*; 6. *New Red Sandstone* (*Corrie Sandstone*); *F. Fault.*

The falls at the head of the gorge are in coarse white and pink mottled sandstone, with thin bands of conglomerate. Above this a strong fault brings in the sandstones and conglomerates of the

Upper Old Red Sandstone for some distance, after which there is another stretch of Calciferous Sandstone lavas and tuffs let down by trough-faulting (Fig. 2).

Sections north and west of Brodick.—A large fault extending to the south on the west side of Maol Donn results in the displacement of the Calciferous Sandstone outcrop of the Uisge nam Fear to the region near Merkland, north of Brodick Castle. From here the outcrop runs S.S.W. until it is lost under the alluvium of Brodick Bay. It reappears in a faulted strip which extends in a west-south-west direction from Brodick Church to Windmill Hill, to the south of the String Road. The Merkland Burn gives a section in basaltic lavas and tuffs north-west of the Summer House in the Brodick Castle policies ; and this strip, faulted once to the south-east, can be traced down to the west of Brodick Castle.

On the slopes to the south of the String Road a small crag and terrace is first encountered on the ascent, which consists of red-stained Calciferous Sandstone basalt lava, very splintery and much crushed. Surmounting this is a thick, well-defined crag and terrace, consisting of coarse white sandstone with occasional pebbly layers. All these beds appear to dip steeply into the hill, *i.e.* to the south-east. It is difficult to say whether the red and white coarse sandstones which succeed the above belong to the Calciferous Sandstone or to the Carboniferous Limestone Series. G.W.T.

Sections in the central area from Glen Dubh to the Clauchan Glen.—By the disruptive action of igneous rocks and of faults the Carboniferous rocks are shifted more than a mile to the southward of the above exposures, and next occur on the south side of Glen Dubh above a wood, and north of a fine set of scars called Creag nam Fitheach. They form a triangular area bounded on the east and west by faults. That on the east side throws down against them the New Red sandstones and conglomerates of Creag nam Fitheach ; that on the west brings up the Upper Old Red Sandstone. The volcanic series of the Carboniferous, dipping southward at angles of 25° to 30°, rests on the Upper Old Red beds at the top of the wood.

South of Brisderg two detached patches of Calciferous Sandstone sediments and lavas occur in Benlister Burn, on either side of a synclinal, the centre of which is occupied by New Red Sandstone. They are associated with small exposures of Carboniferous Limestone Series and Coal Measures (p. 68). W.G.

The much-broken strip of Carboniferous rocks which lies south of the Central Ring Complex, in the tract about Cnoc a' Chapuill, belongs entirely to the Calciferous Sandstone subdivision, *i.e.* to beds below the Corrie Limestone. This limestone crops out in Benlister Glen ; but in the present locality it is overlapped by the New Red Sandstone rocks, which rest unconformably on the red shales and mudstones below the limestone. These red shales, dipping south-east at 40°, are visible in the highest part of the northern branch of the Sliddery Water,[1] and are probably underlain by the volcanic series of the Calciferous Sandstone. A large fault with a downthrow to the north and a direction about E.S.E., shifts both shales and volcanic rocks a considerable distance eastward, so that the former crop out in the same burn where its course is towards the south-west. It runs nearly along the strike, and exposes beds of red sandy clay or shale, purplish red sandstone, and red arenaceous tuffs, the whole much invaded by dykes and sheets of basalt and felsite. The dip of these rocks is generally to the south-east at angles of 30° to 40°, the direction changing to nearly due south at the junction of the two streams south-east of Cnoc a' Chapuill. Just above the junction in the lower part of the other branch stream red mudstones and reddish and grey shale may be observed, with rootlets of plants in places.

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[1] This higher part of the stream is omitted from the Ordnance maps.

Almost the only exposure of the volcanic series occurs in the Allt Mòr, which runs southward on the east side of Cnoc a' Chapuill. A northwardly-running fault appears to shift the Carboniferous rocks farther to the north, and in the stream upward to the west of this, there are found many traces of ash and lava, which appear to alternate several times. The whole section is, however, much obscured by intrusive dykes and sheets, as in the more easterly burn. The tuffs and the massive rocks are nearly always stained a red or purplish colour, as are also the shales and sandstones which are occasionally met with. The dip is south, so that the stream crosses the strike nearly at right angles, and the amount varies from 20° to 40°.

All these beds strike at the hill of Cnoc a' Chapuill, on which there is no trace of them, nor can they be seen on the north of the hill; and though there is fair evidence that this hill is faulted on both sides, it seems also very probable that the Carboniferous rocks are here overlapped by the newer formation. On the western side of the hill, and about 200 yards south of the O.S., there are found traces of the volcanic series in the form of red tuff and ashy red clay, which dip to the south. Westward from this point there are wide spreads of thick peat, and the boundary between these rocks and the overlying New Red Sandstone becomes very obscure. The volcanic zone is no more seen, and the strip of Carboniferous rock, if any exist, is probably shifted about, as represented on the map, by the faults which appear to throw the New Red rocks. To the south of the Clauchan Glen, high upon the hillside, and about 1½ miles west of Cnoc a' Chapuill, a limestone has been quarried in several places. This is a cherty and pebbly rock which dips south at about 20°, and is presumed to be identical with that which occurs as a cornstone at the base of the Carboniferous to the north of Corrie and near the Fallen Rocks. In the most westerly of the quarries the limestone is light in colour and massive, and the more siliceous parts project on a weathered surface. But the whole appears so pebbly that it must be difficult to find any part pure enough for lime-burning. It is overlain by some shales, and 5 to 6 feet of carious sandstone and limestone. Some beds of conglomerate, which come above these, have been classed with the Carboniferous rocks.

On the west this limestone and the associated rocks appear to be cut off by a large fault running N.N.W. Eastward the limestone can be traced by small quarries and swallow-holes for a quarter of a mile, when it is shifted 100 yards to the south by a fault with a north-easterly trend, which has a downthrow to the north-west. The limestone, which everywhere preserves its usual character, has been worked a little on the eastern side of this fault in a long narrow quarry, but all trace of it to the eastward disappears. W.G. (MS.)

Examination of the slices of the Calciferous Sandstone lavas of Arran in the Survey collection shows that they are all olivine-basalts of Craiglockhart and Dalmeny types. Craiglockhart basalt is represented by five specimens, all from the shore section north of Corrie (9396–8; 5658–9). Some of these rocks are beautifully fresh; others have undergone extensive serpentinisation and hæmatisation (9397–8). The fresh rocks show phenocrysts of purplish augite and olivine, up to ½-cm. in diameter, in an intergranular groundmass consisting of labradorite laths with augite and magnetite granules. The latter are wedged in between the felspars which exhibit a marked flow texture. The augite phenocrysts are frequently zoned, and have narrow exterior bands of a slightly darker tint than the interiors, which are often spongy with inclusions of groundmass material. While a few crystals are sharply euhedral, the majority are of irregular embayed outline, and have obviously suffered some magmatic corrosion. The olivines are usually serpentinised, but are occasionally found fresh. The phenocrysts of this mineral are more numerous, but are generally much smaller than the pyroxene.

Dalmeny basalts are to be found in the Uisge nam Fear section south of High Corrie (2148); in the exposures north of the String Road, 500 yards north of Windmill Hill (6997); and from east of Lag na Croise, Benlister Glen (6995). All of these rocks show numerous serpentinized and hæmatized microphenocrysts of olivine, in an intergranular groundmass consisting of labradorite, augite, and iron-ores. The Uisge nam Fear rock contains a few small microphenocrysts of augite in addition to olivine, and may be merely a fine-grained type of Craiglockhart basalt.

A well-bedded tuff of this volcanic horizon from a tributary to the Benlister Burn a quarter of a mile south-east of Brisderg (25049) is a bright red rock which, in thin section, shows numerous, sharply-angular grains of quartz embedded in an opaque, richly-ferriferous matrix, consisting of hæmatized debris of basaltic lava. In this tuff are found hard concretions (25075) of a red-and-pink mottled rock, in which the hæmatite has segregated into small irregular masses, whilst the rounded lava fragments, of which the rock is mainly composed, are thoroughly bauxitized. Another specimen from the exposures north of Creag nam Fitheach, Glen Dubh (6996), is of much the same character, but is richer in quartz and sandstone debris. G.W.T.

CHAPTER VII

THE CARBONIFEROUS ROCKS (*continued*)

Carboniferous Limestone Series and Coal Measures

As the Carboniferous Limestone Series and the Coal Measures (with the Millstone Grit)[1] are inseparably associated in Arran, it becomes advisable to describe the two together. Rocks belonging to these series are found in the north-eastern coastal exposures; in the sections at and near Corrie; in the group of outcrops from the Merkland Burn north of Brodick to Windmill Hill south of the String Road; in the Benlister Burn, west of Lamlash; and in the exposures at the head of the southern branch of the Sliddery Water. There is almost certainly an offshore occurrence to the north of Catacol (p. 69).

THE LAGGAN SECTIONS

The main or Hurlet limestone is here considerably thicker than elsewhere in the island, and is overlain at some distance by two other dark calcareous bands which are not represented at Corrie, and may be the equivalents of the Hosie limestone. The highest of these three limestones occurs nearly a quarter of a mile north-west of the shepherd's house, at a point where the shore-line bends westwards, and coincides with the strike of the beds. The section of these three limestones is as follows, in descending order :—

	Ft.
Black, hard calcareous shale and shaly limestone ..	10 to 12
White sandstone, some of it coarse and pebbly ..	about 60
Black, hard, calcareous shale with limestone in middle ..	10 to 12
Coarse sandstone with a little black shale	30
Thick Corrie Limestone with calcareous shale below ..	35
Blocky sandstone.	

These beds all dip northward at 40°. All the limestone contains many fossils belonging to the following :—

Crinoid stem
Archæocidaris urei (*Flem.*)
Rhombopora sp.
Polypora sp.
Athyrid
Chonetes laguessiana *de Kon.*
Orthotetid
Productus *aff.* giganteus (*Mart.*) [no furrows]
P. longispinus ? *J. Sow.*
P. *cf.* pugilis *Phill.*
Schizophoria sp.
Spirifer *aff.* bisculatus *J. de C. Sow.*
S. *aff.* trigonalis (*Mart.*)
Spiriferina octoplicata ? (*J. de C. Sow.*).

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[1] The question as to how much of the Millstone Grit is involved in these sections must be deferred pending further investigation. Mr. G. V. Wilson, however, has found the bauxitic clays of the Millstone Grit horizon in North Ayrshire, in the Merkland Burn section (*see* 'The Ayrshire Bauxitic Clay,' *Mem. Geol. Surv.*, 1922, pp. 5, 8, 24).

The shale pavement of the limestone, though fossiliferous, has not yielded fossils of diagnostic value such as would point to the presence of the 'Hurlet Fauna' of Central Scotland. *Strepsodus portlockii* (Portl.) was obtained here.

The black shales above have yielded :—

Archæocidaris urei (*Flem.*)
Rhabdomeson sp.
Camarotœchia pleurodon (*Phill.*)
Orbiculoidea nitida (*Phill.*)
Lingula mytiloides *J. Sow.*
Productus *cf.* concinnus *J. Sow.*
P. *cf.* longispinus *J. Sow.*
P. sp., finely striated form
Spirifer semicircularis *Phill.*
Spiriferina octoplicata (*J. de C. Sow.*)
? Amussium concentricum *Hind*
Aviculopecten dissimilis (*Flem.*)
A. clathratus (*M'Coy*)
Edmondia josepha *de Kon.*
E. pentonensis *Hind*
Myalina flemingi (*M'Coy*)
M. verneuilii (*M'Coy*)
Pinna flabelliformis (*Mart.*)
Protoschizodus axiniformis (*Portl.*)
Sanguinolites variabilis *M'Coy*
Sedgwickia gigantea *M'Coy*
Syncyclonema sowerbyi (*M'Coy*)
Conularia quadrisulcata *J. Sow.*
Naticopsis globosa (*Hoeningh.*) [*de Kon.*]
Nautiloid
Orthoceras
Elonichthys robisoni (*Hibb.*).

The upper bed of black shale and shaly limestone referred tentatively in the section above to the Hosie limestone contains the following assemblage :—

Cardiopteris nana (*Eichwald*)
Archæocidaris urei (*Flem.*)
Cf. Ambocœlia urei (*Flem.*)
Composita ambigua (*J. Sow.*)
Hustedia radialis (*Phill.*)
Lingula mytiloides *J. Sow.*
L. squamiformis *Phill.*
Orbiculoidea nitida (*Phill.*)
Productus longispinus *J. Sow.*
P. pugilis *Phill.*
P. *cf.* concinnus *J. Sow.*
Actinopteria persulcata (*M'Coy*)
Allorisma variabilis (*M'Coy*)
Aviculopecten clathratus (*M'Coy*)
A. knockonniensis (*M'Coy*)
Edmondia josepha *de Kon.*
E. laminata (*Phill.*)
E. rudis ? *M'Coy*
Lithodomus lingualis (*Phill.*)
Nuculana lævistriata (*M. and W.*) [*Hind*]
Pinna flabelliformis (*Mart.*)
Sanguinolites variabilis *M'Coy*
S. striato-lamellosus *de Kon.*
S. tricostatus (*Portl.*)
? Scaldia fragilis *de Kon.*
Syncyclonema sowerbyi (*M'Coy*)
Euomphalus carbonarius *J. de C. Sow.*
Euphemus urei (*Flem.*)
Macrocheilina acuta (*J. de C. Sow.*)
Naticopsis
? Cœlonautilus subsulcatus (*Phill.*)
Goniatite
Orthoceras
Megalichthys
Palæoniscid scales.

A fault trending north with a downthrow west crosses these limestones, the lowest of which can be traced as far as the footpath to the westward, but beyond this it is unknown. On the shore where the coast-line again trends north-west there is a pretty example of a sharp syncline in sandstone with thin, dark shale bands. This extends for about 50 yards, and appears to be bounded by a north-east fault. North of this the dip increases from 30° to 60°. The rocks are mostly sandstones with some bands of black shale and flags, and in one place there is a thin ironstone. South of the ruins of the old salt pans we come upon the crop of the coal or coals worked on this coast, and which have no representatives at Corrie. The coal was worked here upwards of a century ago, and there have been somewhat different accounts given of it. All agree, however, that it was a kind of blind or glance coal, which burned without much smoke or flame—an anthracite, in fact. Headrick, who first described these workings [1] in detail, states—'there are three or four seams of coal running parallel from north to south, the principal or main seam being 14 feet in thickness'; but this statement is hardly credible, especially when compared with an account of a working which he got from a Mr. Cowie who had wrought the coal. Mr. Cowie's description was as follows: 'The seam of coal at the Cock of Arran, wrought by James Cowie, is first about 10 inches, then 8 or 10 inches of a dauchy till, then 20 inches of coal . . . the till between the two seams of coal seems to burn lime.' The dauch or till was always mixed with the blind coal in burning lime. It seemed to kindle more readily than the coal; and the only difference was that the dauch always left a large *guest* (cinder), whereas the coal burnt into a fine white ash of very small quantity. The thicknesses above given are very much less than 14 feet, when added together, and in fact do not amount to 4 feet, which thickness we may confidently give as the utmost it attained. Two outcrops have been traced, but it seemed probable these were two sets of workings in one and the same coal separated by a fault. Near the salt pans *Lepidodendron veltheimianum* (?) was collected, and 140 yards north-west of the old ruins there is a hard, brown weathering, argillaceous limestone in the position apparently of the Index or *Productus latissimus* limestone. This bed appears to be 5 or 6 feet in thickness, and has yielded :—

> *Archæocidaris urei*, a *Polypora*, *Lingula mytiloides*, and *L. squamiformis*, an Orthotetid, a doubtful *Productus latissimus*, and a small gasteropod.

The section above this is a good deal obscured, but some 70 yards farther along the shore, where the dip is N.W. at 50° or 60°, there is obscurely seen a thin band of dark-coloured limestone associated with hematite bands. Some 450 yards, or a quarter of a mile north-west of the salt pans, in a small bay, are tessellated ferruginous beds with an ironstone band where were collected :—

Camarotœchia pleurodon (*Phill.*)
Giganteid Productus
Aviculopecten *aff.* knockonniensis (*M'Coy*)
Edmondia ?
? Eumicrotis
Myalina verneuilii (*M'Coy*)
Nucula gibbosa *Flem.*
Streblopteria ornata (*R. Eth.*)
Sanguinolites striato-granulatus *Hind*
Protoschizodus axiniformis (*Portl.*)
? Bucanopsis decussata (*Flem.*)
Euphemus urei (*Flem.*), large
Orthoceras.

At the same spot, in bands overlying the ironstone, were collected :—

Allorisma sulcata (*Flem.*)
Edmondia rudis *M'Coy*
Nucula gibbosa *Flem.*
Nuculana attenuata (*Flem.*)
Streblopteria lævigata (*M'Coy*)
S. ornata (*R. Eth.*)
Euphemus urei (*Flem.*)
Orthoceras
Cladodus striatus *Ag.*

The beds here dip northward at 20° to 25°. Beyond these we pass over an alternating series of sandstones and clays on to a thick blocky sandstone which forms a kind of headland. The coast now trends more westerly, and we soon come upon a fault running at right angles to the shore which throws down on the east 20 to 30 feet. Beyond this we get a portion of the beds repeated, and soon we arrive at a red limestone in which *Productus latissimus* is abundant. This is more than a quarter of a mile south-east of the junction with the New Red rocks. It is bounded by a fault on the west side, which must be an upcast to the east, and is apparently some 15 feet in thickness. It has yielded :—

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[1] *See* his 'View of the Mineralogy, etc., of the Island of Arran,' 1807, pp. 212–219.

Chætetid, laminar form
? Zaphrentid, indet.
Crinoid joints
Archæocidaris urei (*Flem.*)
Fenestella
Tabulipora scotica *Lee*
Chonetes laguessiana *de Kon.*
Composita ambigua (*J. Sow.*)
Leptæna analoga (*Phill.*)
Productus antiquatus *J. Sow.*
P. latissimus *J. Sow.*, rather narrow form
P. pugilis *Phill.*
P. *aff.* lobatus *J. Sow.*
Schizophoria resupinata (*Mart.*)
Spirifer triradialis *Phill.*
S. sp.
Spiriferina octoplicata (*J. de C. Sow.*)
Nucula gibbosa *Flem.*
Nuculana attenuata (*Flem.*)
Phillipsia mucronata *M'Coy*

Nearly 100 yards west from this spot and 375 yards south-east of the New Red junction occurs a thin 'cephalopod limestone' about 2 feet in thickness, which yielded :—

> *Composita ambigua* (J. Sow.), a bisulcate *Spirifer*, a small giganteid *Productus* similar to the form occurring in the Upper Limestone group of Central Scotland, and two indeterminable Nautiloids ; one a large, smooth form, while the other is strongly tuberculated (? *Pleuronautilus*).

A few yards west of this, in bands overlying the cephalopod limestone and 365 yards south-east of the New Red junction, there were got :—

Cf. Ambocœlia urei (*Flem.*)
? Composita ambigua (*J. Sow.*)
Dielasma ?
Productus muricatus *Phill.*
P. pugilis *Phill.*
P. scabriculus ? (*Mart.*)
? Schellwienella crenistria (*Phill.*)
Nucula gibbosa *Flem.*
Nuculana attenuata (*Flem.*)
Orthoceras.

A few yards farther west and 350 yards south-east of the New Red rocks, there were collected :—

> ? *Edmondia*, *Sanguinolites clavatus* (Eth.) and *Solenomorpha parallela* (Hind).

Above these beds comes a brecciated-looking limestone of considerable thickness, which is repeated by a fault ranging N.N.E. This only yielded a compound coral. It has been called the Coral limestone.

Some of the upper limestones crop out on the hillside a quarter of a mile west of Cock Farm, and from one of these were obtained :—

Chætetid, cast of
Crinoid ossicles
Fenestella
Productus latissimus *J. Sow.*
Cf. Schellwienella crenistria (*Phill.*)
Allorisma sulcata (*Flem.*)
Myalina verneuilii (*M'Coy*)
Macrocheilina
Dentaliid
Trilobite, indet.

A thin limestone occurs in the faulted strip of Allt Mòr, between North Newton and the Cock of Arran.

Above the Coral limestone on the shore the beds consist largely of shales and red clays, with some rough and irregular sandstones. The highest marine band noticed was 100 yards south-east of the New Red junction, and here were obtained :—

Lingula mytiloides J. Sow., *Productus muricatus* Phill., *Schellwienella crenistria* (Phill.), *Spirifer semicircularis* Phill., and crinoid ossicles.

Coal Measure plants were obtained from a spot 72 yards south-east of the New Red rocks :—

Calamites sp.
Cordaites principalis (*Germar*)
Lepidostrobus ?

A larger and more important set was collected from a locality 20 yards south-east of the New Red junction, and these are the following :—

Calamites ramosus *Artis*
,, varians *Sternb.*
Cordaites principalis (*Germar*)
Mariopteris muricata (*Schloth.*)
Neuropteris gigantea *Sternb.*
,, sp.
Sphenophyllum myriophyllum *Crépin*
,, sp.

SECTIONS AT AND NEAR CORRIE

The Corrie Limestone (Fig. 1), which occupies the old harbour, is probably the equivalent of the Hurlet. It is said to be 20 feet in thickness, and is crowded with innumerable specimens of *Productus giganteus,* well exposed on the under surfaces of many of the beds in the old quarry to the westward, which extends for nearly a quarter of a mile up the hillside. The beds of limestone are separated by thin partings of reddish shale, and from the calcareous shale immediately overlying the limestone were obtained by the fossil-collector of the Survey, Mr. Tait, a number of species the list of which is :—

Rhabdomeson, casts of
Pinnatopora
Chonetes laguessiana *de Kon.*
C. sp. (larger than C. laguessiana)
? Cleiothyridina roissyi (*L'Ev.*)
? Dielasma
Productus costatus *J. de C. Sow.*
P. giganteus (*Mart.*) [furrows do not reach umbo]
P. latissimus *J. Sow.*
P. productus (*Mart.*)
P. scabriculus (*Mart.*)
P. *aff.* longispinus *J. Sow.*
P. (Pustula) *cf.* elegans *M'Coy*
Schellwienella crenistria (*Phill.*)
Spirifer *aff.* trigonalis (*Mart.*)
S. *cf.* semicircularis *Phill.*
Spiriferina octoplicata (*J. de C. Sow.*)
Aviculopecten dissimilis (*Flem.*)
A. sp., finely striated
Cf. Crenipecten semicircularis (*M'Coy*)
? Leiopteria
Lithodomus lingualis (*Phill.*)
? Modiola
Myalina flemingi (*M'Coy*)
M. peralata *de Kon.*
? Pinna mutica *M'Coy*
Protoschizodus obliquus (*M'Coy*)
Euphemus urei (*Flem.*)
Naticopsis globosa ? (*Hoeningh.*) [*de Kon.*]
Pleurotomariid
Cf. Porcellia mosana *de Kon.*
Gasteropod indet.
Actinoceras
Orthoceras sulcatum *Flem.*
O. sp.
Nautiloid
Phillipsia mucronata *M'Coy*
Megalichthys
Polyrhizodus magnus *M'Coy*
Rhadinichthys ornatissimus (*Ag.*)
Xystrodus striatus (*M'Coy*)

Two basic dykes cross the limestone in a north-north-west direction. One of these, just above the old lime-kiln, is 5 feet wide, and the other, nearly 50 yards higher up, is 4 feet in width. Several small faults also cross the quarry. One of these above the kilns coincides with one of the dykes just mentioned, and it throws down east 7 to 8 feet. A second fault a little farther up, throws down 2 feet to the west, and a third fault is down east 3 to 4 feet. Near the top of the quarry there is the following section :—

	Ft.
Sandstone	6
Shale and shaly sandstone	3
Sandstone	10 to 12
Shale and shaly sandstone (red)	3 to 5
Limestone, upper bed .. at least	16

There are slight calcareous shale partings where *Producti* are very numerous.

Between the two upper faults the *bearing* above the limestone is much less, being only 10 to 15 feet, but east of this there is probably 30 feet of sandstone and shale in the artificial cliff above the limestone. The two shale bands are variable, but the intermediate sandstone is not so thick and massive as near the top of the quarry, while 10 to 12 feet of the upper sandstone appears.

Headrick (*op. cit.*, p. 344) gives some analyses of limestone at Corrie, from which it appears that the proportion of carbonate of lime varies from 90½ to 97 per cent. He also gives the following for South Corrie Quarry :—

Carbonate of Lime	98½
Clay	1½

This is probably the old quarry at An Sgriob, north of Maol Donn, which is in the same bed as the Corrie Quarry, and which has also yielded a numerous suite of fossils. W.G., G.W.L.

The An Sgriob quarry appears to be an enlargement of a cliff-section in a small stream. It has not been worked for many years, but still shows the section illustrated on top of next page.

Bed 6 probably belongs to the Coal Measures. It rests on the limestone in the eastern part of the quarry (Fig. 3), then successively on the sandstone (bed 4), and on bed 5. This junction may represent an unconformity between the Coal Measures and the Carboniferous Limestone Series. Bed 4 is lenticular, and fades out in a distance of a few feet. A thin dyke of crinanite cuts the series in the western part of the quarry. The shale (bed 1) is calcareous towards the top of the bed, and contains one or two thin limestone bands, and numerous red-stained limestone nodules which are very fossiliferous. The thick limestone (bed 3) is crowded with large Productids.

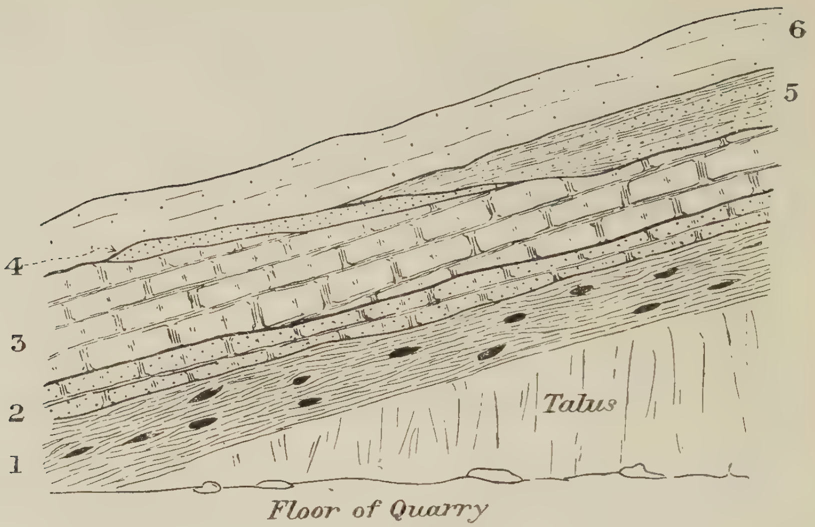

FIG. 3.—*Section in An Sgriob Quarry, Corrie.*

6. *Red sandstone, with plant remains (Coal Measures and Millstone Grit).*
5. *Thin-bedded red sandy shale with ribs of sandstone, 7½ feet.*
4. *Lens of coarse red gritty sandstone, 3¼ feet.*
3. *Limestone with partings of shale, 14 feet.*
2. *Sandy red limestone, with shale partings ; thickness uncertain.*
1. *Red and grey shale, calcareous at top, 17 feet.*

Carboniferous Limestone Series.

G.W.T.

The shales below the limestone have yielded the following suite of fossils :—

Crinoid stems
Archæocidaris urei (*Flem.*)
Fenestella
Rhabdomeson ?
Cf. Camarotœchia pleurodon (*Phill.*)
Chonetes laguessiana *de Kon.*
Dieslasma hastatum (*J. Sow.*)
Productus concinnus *J. Sow.*
P. productus (*Mart.*)
P. scabriculus (*Mart.*)
P. sp., giganteid
P. sp., small, finely striated
Spirifer grandicostatus *M'Coy*
S. *aff.* duplicosta *Phill.*, with finer ribbing.
S. sp., elongate form
Allorisma sulcata (*Phill.*)
Aviculopecten
Edmondia sulcata (*Phill.*)
Leiopteria squamosa (*Phill.*)
Myalina flemingi (*M'Coy*)
Nucula gibbosa *Flem.*
Pinna flabelliformis (*Mart.*)
Protoschizodus axiniformis (*Portl.*)
P. obliquus (*M'Coy*)
Pseudamussium ellipticum (*Phill.*)
Pterinopecten radiatus (*Phill.*)
Sanguinolites striato-granulatus *Hind*
Syncyclonema sowerbyi (*M'Coy*)
Bucanopsis decussata ? (*Flem.*)
Euomphalus
Euphemus urei (*Flem.*)
Loxonema
Macrocheilina
Cf. Naticopsis planispira *de Kon.* [*non Phill.*]
Zygopleura
Dentaliid
Orthoceras cylindraceum *Flem.*
O. sulcatum *Flem.*
? Temnocheilus
Palæoniscid scales

The beds between the Corrie Limestone and the Index Limestone are well exposed on the shore for 220 yards south of the old harbour, and consist mainly of alternations of thick white sandstones and flags, with occasional shale bands. The dip continues much the same in amount and direction, 20° to 30° towards the south-east. The sandstones have been much quarried for building material in the wood above the houses, and at the landing place. There is an ironstone band in one place, and fireclays, such as often underlie coal-seams, occur, but there are no coals, though we are on the horizon of the coals worked at the north end of the island near the Cock. There are traces of coal plants however. The thickness of this part of the series must be about 250 feet.

A thin red limestone with *Productus latissimus* occurs about 25 yards south of the Ferry rock, and not far to the south of it occur two others, as in the following section in descending order :—

		Ft.
3.	Red limestone, in one place	1
	Shale and sandstone, some of the sandstone fine and like ganister .. .. about	20
2.	Red limestone	1
	Red shale, ...	7 to 8
1.	Red limestone	2 to 3
	Shale, argillaceous, with red and mottled sandstone ..	5

W.G.

No. 1 of this section is the Index or *Productus latissimus* Limestone. It contains few brachiopods apart from *Prod. latissimus* J. Sow. The most characteristic element of the poorly-preserved fossil assemblage consists of small gasteropods of which the most widespread are a form resembling *Macrocheilina polyphemoides* de Kon., but narrower, and small Murchisonids ; others may be referred to *Bucanopsis decussata* (Flem.), *Euomphalus carbonarius* J. de C. Sow., and *Loxonema sp.* Imperfectly preserved lamellibranchs may belong to *Edmondia* and to *Sanguinolites.* Cephalopods are represented by an indeterminable Nautiloid.

No. 2 band has yielded almost exclusively minute gasteropods difficult of determination, belonging to *Macrocheilina* and to Murchisonids, the latter of which include *Murchisonia* and *Aclisina.* It is doubtful whether the specific names given to these small fossils on p. 41 of the first edition of this Memoir would stand to-day. A tooth of *Strepsodus striatulus* Traq. was also obtained.

Lamellibranchs, among which the more conspicuous are *Nucula scotica* Hind, *N. luciniformis* Phill., *Nuculana attenuata* (Flem.) and *Allorisma sulcata* (Flem.), give a slightly different faunal aspect to No. 3 band, where the small gasteropods mentioned above still occur.

G.W.L.

There are numerous small faults about this part of the shore which in the main run parallel to the coast-line, crossing the beds nearly at right angles, and shifting their outcrops again and again for a few feet. A mass of sandstone now projects into the sea and south of this, in front of the hotel, is a little bay in which occur two or three thin red limestones, from 1 to 2 feet thick, which are probably separated by shale, but the section is not clear. To the south of this bay there is a mass of sandstone with irregular shale bands. One of the shale bands, 8 to 10 feet thick at the shore-line, gradually thins away seaward, till at low-water mark it has almost disappeared. The thick sandstone underlies a mass of red and mottled clays, red and purplish shales, with occasional thin sandstones which occupy the larger bay south of the hotel. The beds in this bay are classed with the Coal Measures as they contain organic remains of Upper Carboniferous facies, but they and the equivalent beds elsewhere may possibly be Millstone Grit. About 25 yards south of the northern boundary of Cromla gardens, and near high-water mark, there was obtained a specimen of *Neuropteris gigantea* Sternb., and opposite the Cromla House the beds yielded *Lepidodendron sp.*, *Carbonicola acuta* (J. Sow.), *C. aquilina* (J. de C. Sow.), and *Naiadites modiolaris* (J. de C. Sow.).

These Coal Measures strata also crop out in the lower part of Locherim Burn 200 yards from the sea, where in fine red shale 15 yards from the faulted New Red junction there were obtained :—

Mariopteris muricata (*Schloth.*)
Neuropteris heterophylla *Brongt.*
Carbonicola acuta (*J. Sow.*)
C. aquilina (*J. de C. Sow.*)
Naiadites sp.

Another locality near Corrie where these beds occur is on the north-west side of the Maol Donn cliff. In red sandy shale above the limestones were found :—

Artisia approximata (*Brongt.*)
Calamites ramosa *Artis*
C. sp.
Neuropteris gigantea *Sternb.*
N. sp.
Stigmaria sp.

There is another fossiliferous band up the Locherim Burn the existence of which was first made known by Prof. W. Ivison Macadam,[1] but it is in the Upper Limestone Series some 330 yards from the sea, where the stream forks at a waterfall, and it is separated by a fault from the Coal Measures strata previously mentioned. Alternations of shale and sandstone occur with a thin limestone band. The beds above the limestone yielded the following plants to the Geological Survey collectors :—

Asterocalamites scrobiculatus (*Schloth*).
Carpolithes sulcata *L. & H.*
Lepidodendron veltheimianum *Sternb.*
Lepidostrobus sp.
Rhodea sp.
Sigillaria taylori *Carr.*
Sphenopteridium dissectum (*Göpp.*)
Stigmaria

The limestone and calcareous shale band underlying the plant bed afforded :—

Schizophoria resupinata (*Mart.*)
Cf. Schellwienella crenistria (*Phill.*)
Productus sp.
Allorisma sulcata (*Flem.*)
Edmondia unioniformis (*Phill.*)
Myalina verneuilii (*M'Coy*)
M. sp.
Nucula gibbosa *Flem.*
Nuculana attenuata (*Flem.*)
Protoschizodus axiniformis (*Portl.*)
P. obliquus (*M'Coy*)
Bellerophontid
Macrocheilina sp.

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[1] See his paper entitled 'Notice of a New Fossiliferous Bed in the Island of Arran,' *Trans. Geol. Soc. Edinburgh*, vol. v., 1887, p. 316.

In the Merkland Burn about three-quarters of a mile north of Brodick Castle there is a fairly continuous outcrop of the Carboniferous rocks, except that the section is obscured where the Corrie Limestone should appear. The thick sandstones above it appear, and lower down the burn two of the Upper Limestones. From the lowest of these were collected :—

Crinoid ossicles
? Cleiothyridina roissyi (*L'Ev.*)
Composita ambigua (*J. Sow.*)
Orthotetid
Productus *cf.* muricatus *Phill.*
Allorisma sulcata (*Flem.*)
Edmondia josepha *de Kon.*
Lithodomus lingualis (*Phill.*)
Pectiniform shell

The limestone a few yards still lower down the stream yielded *Productus latissimus*. The more shaly beds still farther down the stream are similar to the highest beds on the Corrie shore, and from them were obtained the following Coal Measures forms :—

Anthracomya modiolaris (*J. de C. Sow.*)
Carbonicola acuta (*J. Sow.*)
C. acuta *var.* rhomboidalis *Hind*
Naiadites quadrata (*J. de C. Sow.*)
Megalichthys hibberti *Ag.*
Rhizodopsis sauroides (*Will.*)

The same beds in a parallel burn nearly a quarter of a mile to the south-west of this gave *Carbonicola acuta, C. aquilina, Rhizodopsis sp.* All these beds have a steep dip to the E.S.E., and the dip increases towards Brodick Castle. The Corrie Limestone was at one time quarried at the edge of the wood about half a mile north of the Castle, and there are traces of small limestone quarries west of the Castle. In the Sawmill stream 300 yards south-west of the Castle the beds are practically vertical. Here, a few yards above a foot-bridge, were collected the following :—

Productus latissimus *J. Sow*, [small]
P. scabriculus (*Mart.*)
Aviculopecten *cf.* dissimilis (*Flem.*)
Bellerophontid
Zygopleura rugiferum (*Phill.*)
Z. *aff.* murchisonianum (*de Kon.*)
Gasteropods, with low spire, 2 forms
Gasteropod, conical with spirally striated base
Orthoceras indet.

They must belong to the Upper Limestone Series. In the mill-lade *Lingula squamiformis* Phill. was found. Shelly ironstone bands associated with shales and sandstones are found in the Rosa Burn on either side of the bridge near Brodick Manse, and from one of these, a few yards above the bridge, a 'musselband ironstone,' there were obtained a Lycopod branch and a species of *Carbonicola*. Here we have the Coal Measures again.

The Corrie Limestone was formerly quarried north-west of the church, just beyond the boundary wall of the kirkyard ; and on the hillside a quarter of a mile south-east of the String Road and half a mile and upwards west of the wood. The beds are nearly vertical in both localities and they yielded *Productus giganteus* (Mart.). The Carboniferous rocks here have diminished to a thickness of not more than 600 feet, and yet we have the Coal

Measures above and the volcanic series below; but there is no trace in Glen Shurig of the Upper Limestones.[1]

The next exposure of Carboniferous rocks is found about a mile to the south of the above locality, on the south side of Glen Dubh, where it forms a triangular patch bounded on the east and west by faults (see p. 55). In the southern angle of the triangle massive white sandstone, which probably overlies the Corrie Limestone, is seen, but the limestone itself does not crop out, and no other beds are to be observed. Near the west end of Creag nam Fitheach another and still smaller Carboniferous patch occurs which is faulted on either side, but no other rock is visible than the volcanic zone.

South of this small isolated patch and beyond Brisderg, two other detached areas of Carboniferous rocks occur in Benlister Glen, on either side of a synclinal, the centre of which is occupied by Trias. It would seem that the unconformity between the two formations is more marked here than in any other part of the island yet described, for in one place beds containing plants and animals of Coal Measures age occur, while elsewhere the New Red rocks rest directly upon the Corrie Limestone or even overlap that bed and repose on the shales below. On the western side of the synclinal the Corrie Limestone may be seen at Benlister Burn, nearly half a mile south-south-west from Brisderg. It appears to be repeated by a fault on the north side of the burn, but must be several feet in thickness, and from it have been collected numerous fossils, all in a poor state of preservation:—

Crinoid joints
Archæocidaris urei (*Flem.*)
Fenestella
Cleiothyridina roissyi (*L'Ev.*)
Composita ambigua (*J. Sow.*)
? Dielasma
? Hustedia radialis (*Phill.*)
Productus concinnus *J. Sow.*
P. giganteus (*Mart.*)
P. latissimus *J. Sow.*
P. scabriculus (*Mart.*)
P. *cf.* muricatus *Phill.*
? P. fimbriatus *J. de C. Sow.*
Cf. Schellwienella crenistria (*Phill.*)
Schizophoria ?
Spirifer bisulcatus *J. de C. Sow.*
S. semicircularis *Phill.*
S. trigonalis (*Mart.*)
S. *cf.* duplicicosta *Phill.*
S. *cf.* humerosus *Phill.*
? Spiriferina octoplicata (*J. de C. Sow.*)
? Macrocheilina
Megalichthys sp.
Pœcilodus jonesi *Ag.*

This limestone is overlain by New Red sandstone and conglomerate, while a few yards away, on the south side of the burn, the conglomerate rests immediately on red shaly clay, and the limestone has disappeared. However, nearly 300 yards farther to the south-west the *Productus* limestone appears again for a short distance, but in a very attenuated form (only 3 feet thick) under the conglomerate, but not immediately, and overlying a thick series of red shales and clays, with a few thin tuffaceous bands.

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[1] In the Memoir on Sheet 21 (1903) it goes on to state here that Carboniferous sediments are involved in the felsite of Windmill Hill. A discovery of Mesozoic fossils in 1925 makes it certain that the brick-red and tea-green marls at this locality are Keuper and not Calciferous Sandstone, as stated in the Memoir. It is practically certain that all the sediments entangled with the felsite intrusions of Windmill Hill are Mesozoic (*see* p. 104).

The dip is high, being 50° to 60° towards the south-east, and to the westward comes on the volcanic zone which underlies the red shales. All these rocks are pierced by many acid and basic dykes.

On the eastern side of the synclinal the limestone appears in the southern bank of a small burn 400 yards due south of Brisderg. It is of considerable thickness, and is overlain by several feet of white blocky sandstone, on which rests the Triassic conglomerate. To the westward the conglomerate appears to overlap both the sandstone and limestone, and rests immediately on the red shales below. The greater part of the small valley to the eastward seems to be occupied by these red shales, though not many sections occur in them, owing to a thick deposit of drift, and the Triassic conglomerate appears to form the feature on the west side, which runs southward to a waterfall in the Benlister Burn, where it dips westward. No limestone here appears below the conglomerate, though red shales and sandstone, probably of Carboniferous age, are visible, dipping westward at 35°. However, by following the base of the conglomerate, some 200 yards to the southward, where a small stream occurs, we come upon the limestone again, with the usual *Productus giganteus*. The rocks here are much disturbed however. Lower down the main stream below a fall called Eas Geal (white water), at the bend of the stream there occur some shales and sandstones of a red colour, with a bed of shelly ironstone, dipping steeply to the south-east. This locality is 2¼ miles west of Lamlash Bay, and half a mile south-south-east from Brisderg. These beds have yielded Coal Measures forms like those of Corrie, etc. There were collected here :—

Calamites suckowii Brongt., *Calamites sp.*, and *Carbonicola acuta* (J. Sow.)

These rocks on the west side appear to be faulted against the contemporaneous volcanic zone elsewhere described (*see* latter part of this chapter), and on the east they are thrown against Triassic rocks by a large fault which passes east of Brisderg. Another fault with a throw in the opposite direction passes west of Brisderg, and brings down the Triassic rocks on that side against the Lower Carboniferous zone, which is also bounded on the south side by a fault running eastward, throwing the red shale down against the traps. W.G., G.W.L.

CATACOL CAIRN

The coping of the wall in front of the police station, Lochranza, near the pier, is made of white Carboniferous freestone collected on the foreshore nearly a quarter of a mile north of Catacol, and the coping of the wall round the most easterly house in Catacol is from the same locality and of the same character. At first it seemed possible the materials might have been derived from ballast blocks or from scattered boulders on the shore, but on examining the ridge below high-water mark (called a ‘ cairn ’), whence the stones were obtained, it was found there were still remaining numerous large and not rounded blocks of the white Carboniferous sandstone, and also many blocks of red fossiliferous limestone belonging to the same formation. The sandstone blocks are much too large to have been used for ballast, and if there is not an outcrop of Carboniferous rock near, the ridge must be regarded as a kind of moraine. But the latter explanation does not appear very probable when we consider that the nearest place where rocks of this kind occur *in situ* is more than 2 miles away to the east of North Newton. It seems more likely that the blocks have been cast up by storms from an outcrop not far away, beneath the sea.

There are many limestone blocks in the old dyke by the roadside between Catacol village and the bridge over Catacol Burn, which must also have been derived from the foreshore.

Mr. D. Tait has obtained the following suite of organic remains from the limestone blocks of the ' cairn ' :—

Coral, rugose
Lithostrotion, indet.
Crinoid ossicles
Composita ambigua ? (*J. Sow.*)
Lingula
Productus latissimus *J. Sow.*
P. sp., small giganteid
P. *cf.* antiquatus *J. Sow.*
? Schizophoria resupinata (*Mart.*)
Spirifer
Aviculopecten
Nucula gibbosa ? *Flem.*
Nautiloid, indet.
Phillipsia mucronata ? *M'Coy*

SECTIONS IN SLIDDERY WATER HEAD, SOUTH BRANCH[1]

The Carboniferous area in this locality consists principally of dull-red slaggy lavas and red tuffs, the latter, which vary from fine muds to coarse agglomerates, predominating. Two bands of sandstone and shale, which have yielded plants, shells, and fish remains having a Coal Measures aspect to the fossil-collectors of the Geological Survey, are included. The area over which these rocks extend is roughly triangular, nearly three-quarters of a mile in length from N.E. to S.W., with a breadth of 600 yards at its widest part. It is found in the southern headwaters of the Sliddery Water on the south side of the Ross Road, about 4 miles south-west of Lamlash Pier. These rocks may extend some 200 or 300 yards farther than the most northerly outcrops noticed, and may occupy the drift-covered ground between the main stream and the road.

The rocks, for the most part tinged a deep red or purple, are arranged in an anticlinal form, the axis of which is directed from E.N.E. to W.S.W. Only the southern side of this structure is, however, well exposed, the northern being much obscured by glacial drift. The principal sections are found in three unnamed parallel branch streams which rise in the higher ground to the south, and run north-west across the area. They are here named Burns A, B, and C, for convenient reference. The longest of these is Burn C, which rises on the west side of Cnoc Dubh ; Burn B, the next to the east, is not shown on the One-inch Map ; and the most easterly is Burn A. Sections are exposed in still smaller intermediate streams, and in the main burn which runs parallel to the road, especially in that part of it near the foot of Burn C. The sections are much obscured by the abundance of Kainozoic intrusions.

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[1] This account is somewhat summarized from Mr. Gunn's MS. on Sheet 13. A long detailed account is to be found in a paper by Mr. Gunn, ' On the Old Volcanic Rocks of the Island of Arran,' *Trans. Geol. Soc. Glasgow*, vol. xi., part ii., 1900, pp. 174–191.

The general stratigraphical succession in descending order is as follows :—

Base of New Red Sandstone.
Lavas, very slaggy and amygdaloidal, with occasional tuff bands.
Coarse felspathic grit.
Shales and ironstone bands, with a sheet of intrusive felsite.
Flaggy sandstones and shales passing westward into fine volcanic mudstones. This is the band which has yielded most of the organic remains.
Alternations of fine red volcanic mudstone and tuff, with coarse volcanic ash and ashy sandstone, with sometimes beds apparently of lava.

The base of the series is nowhere seen.

Burn A.—The section in this burn is much obscured by drift. Beds of purplish-red tuff are seen in the lower part of its course, and dip down stream or to the W.N.W. at a low angle. Higher up the burn these rocks are abruptly truncated by a mass of coarse intrusive dolerite, which here bounds the volcanic series on the eastern side. To the south-west, between this burn and the next, there crops out on the hillside a massive red rock, which, in places, resembles a tuff, and in others, a fine-grained lava.

Burn B.—A felsite intrusion occupies the burn for 100 yards or so above its junction with the main stream. Tuffs and fine-grained lava occur above the felsite, and dip north at angles varying from 20° to 10°. In the next 150 yards an undoubted slaggy lava occurs, with intercalated beds of shale and sandstone, and about the waterfall fine red mudstone and shale probably of volcanic origin. The dip lessens to horizontality, and then inclines in the opposite direction, *i.e.* towards the south-east. The most important part of the section is reached 250 yards up the stream from its foot. The fossiliferous bands are partly involved with a mass of intrusive Kainozoic felsite. As far as can be made out, the section is as follows in descending order :—

1. Shale with bands of ironstone, mostly included within the felsite. *Carbonicola* abundant.
2. Sandstone, white, flaggy, and quartzose, with *Stigmaria*. Thickness, 12 to 15 feet.
3. Shale with ironstone band full of shells in places. 8 to 10 feet thick.
4. A thin sheet of grey (? intrusive) basic igneous rock,[1] amygdaloidal at top. About 2 feet thick.
5. Shale, reddish and dark-coloured, some of it towards the base slightly tuffaceous. It contains some ironstone nodules, and seems to pass down into fine red tuffaceous mudstones or shales. Thickness, 8 to 10 feet.

These beds dip to the south-east at an angle of 12°.

It is from the upper part of No. 3 that most of the fossils have been obtained. Some thin bands are crowded with specimens of *Carbonicola* ; and the same horizon has yielded plants and various species of fish. Two species of *Carbonicola*, *C. acuta* (J. Sow.) and *C. robusta* (J. Sow.), and seven of fishes (*see* list below) have been obtained here. The plants were submitted to the late Dr. Kidston, but only one, *Lepidodendron*, could be specifically identified. The following is a complete list of the fossils obtained by the Survey collectors, Messrs. Macconochie and Tait, in 1897, from bed No. 3 :—

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[1] This rock (7741) is a fine-grained quartz-dolerite identical with some members of the suite described in Chapter XII.

Lepidostrobus sp.
Stigmaria sp., abundant
Calamites sp.
Carbonicola acuta (*J. Sow.*)
C. robusta (*J. Sow.*)
C. sp., indet.
Diplodus sp., teeth
Pleuroplax sp., teeth
Helodus sp., teeth *Ag.*
Megalichthys hibberti ? *Ag.*, teeth and scales
Rhizodopsis sauroides ? (*Will.*), scales
Strepsodus sauroides (*Binney*), teeth
Platysomus parvulus *Young*, scales
Lepidodendron veltheimianum *Sternb.*

Subsequently, in 1899, Mr. Tait obtained plants, chiefly *Calamites*, from the red tuff below and near the waterfall, the most abundant form being *Asterocalamites scrobiculatus* (Schloth.), a characteristic Lower Carboniferous form. *Sphenopteris sp.* ? and *Anthrapalæmon* were also obtained.

The section in the upper part of Burn B above the felsite is very poor. It shows red micaceous shale and sandstone underlying a strong band of light-grey, rather coarse, felspathic grit. In 1899, however, Mr. Tait discovered fossils in fine red mudstones, including numerous specimens of *Neuropteris heterophylla* Brongt., a characteristic Coal Measures form, and a specimen of *Spirangium carbonicum* Schimper. This form had previously only been recorded from one other locality in Scotland, Woodhead Quarry, Kilmaurs, Ayrshire, in strata belonging to the lowest member of the Coal Measures.

The grit band mentioned above does not appear in the stream gorge, but forms a conspicuous feature on the hillside, especially to the north-east, where it can be traced for 250 yards. It dips south-east, and, with the whole of the accompanying series, is cut off on the east side by an intrusive felsite mass. Above the grit a slaggy lava, with perhaps one band of tuff, is poorly exposed. The burn at this place is occupied by an interesting composite dyke. The south-eastern boundary of the volcanic series appears to be unfaulted in this place, as a feature strewn with blocks of a whitish sandstone probably marks the oncoming of the New Red Sandstone above.

Burn C.—The most significant section occurs about a quarter of a mile above the main stream. The New Red Sandstone here dips south at 15°, and is followed below by a slaggy lava about 30 feet thick, although the junction is obscured by a felsite dyke. The upper grit and shale band, which comes on beneath the lava, may likewise be about 30 feet thick. A fault occurs here along the burn throwing down about 30 feet to the west. The purple and dark shales yield *Stigmaria* fragments, and from an ironstone band there was obtained by the fossil-collector a small shell (? *Myalina*). Subsequently Mr. Tait obtained *Neuropteris heterophylla* Brongt., *Calamites sp.*, *Lepidophloios*, and some lamellibranchs.

Below this shale comes the intrusive felsite of Burn B; but instead of the fossiliferous shales and sandstones of that stream a mass of barren red shales and volcanic mudstone appears below the intrusive rock. These beds are at first horizontal, but they soon roll over, with a gentle dip to the W.N.W., and then at a high angle. The purple ash in the lower part of the stream appears nearly vertical in places, but the section is much confused by Kainozoic basalt intrusions. These also cut through massive red tuffs and breccias in the main stream, just above its junction with Burn C. Below the junction the dip is very irregular, and vertical in places. It may be that the disturbance is due to a volcanic vent. Farther down the volcanic series is cut off by a basic Kainozoic intrusion, which forms the boundary all along the north-west side. Poor exposures of the lavas and accompanying sediments occur at various places to the west and south-west of Burn C for a distance of a little over 600 yards.

The volcanic series of Sliddery Water Head (south branch) is thus seen to be bounded by a basic intrusion on the north-west side, which probably comes up along a line of fault downthrowing to the north-west. On the east it is bounded by intrusive masses of dolerite and felsite, except for a short distance immediately south of the Ross Road, where glacial drift obscures all the relations. Only along its southern border, therefore, can anything be learnt as to its relations to the overlying New Red Sandstone. These succeed to the south, and are presumed to rest unconformably on the volcanic series, but the evidence is not conclusive, and the data for the general unconformity between the Carboniferous and the New Red Sandstone has been obtained from other Arran localities. To account for the fact that the New Red Sandstone rocks are here reposing on beds of Coal Measures age, while a mile away to the north-west they rest on Lower Carboniferous rocks, it must be supposed that in the intermediate area the unconformity between the two formations is much more decided than it has been found to be elsewhere in the island, or that there is concealed here a post-Carboniferous fault which threw down these higher rocks (Coal Measures) against the Carboniferous Limestone Series before the deposition of the New Red Sandstone. W.G. (MS.)

Three slices of the Upper Carboniferous lavas of Arran are available in the Survey collection. These are all from the exposures at the head of the Sliddery Water described in the preceding section; two are from Burn B (7051, 7740), and one from Burn C (7739). The last-named is the freshest and most typical rock. It shows numerous serpentinized microphenocrysts of olivine in a groundmass of straight-extinguishing plagioclase laths (oligoclase), and iron-ores (magnetite and hæmatite). The groundmass possesses a poorly-developed flow texture through the sub-parallel arrangement of the felspar microlites. The other two rocks are entirely similar, except that they are more decomposed with a more profuse development of secondary iron-ores. The affinities of these rocks are clearly with the mugearites.

Four slices of the tuffs from Sliddery Water Head have also been examined. Three of these (6994, 7738, 7742) show about equal admixtures of quartz grains and volcanic fragments. The latter are all of mugearitic characters, and are often rounded, although some large fragments (1 cm. diameter in 7738) have extremely irregular embayed shapes. While some of the lava fragments are still comparatively fresh, the majority of them are more or less hæmatized. The matrix in which both quartz grains and lava fragments are embedded is a decomposed aggregate of fine volcanic detritus. The remaining specimen (6371) is well bedded, and is so rich in quartz that it is best regarded as a tuffaceous sandstone. G.W.T.

CHAPTER VIII

THE NEW RED SANDSTONE

Lower Division (Permian)

THE rocks occurring above the Carboniferous in Arran form a continuous series of red sandstones, breccias, conglomerates, and shales, passing upwards into a more variegated and calcareous group, which may be comprised as the New Red Sandstone. Its main area of distribution is in the southern half of the island, south of the annular belts of older rocks which encircle the two principal Kainozoic igneous centres. There is also a coastal strip extending from Brodick to Corrie, and two outliers near the Cock of Arran. In the south the formation is riddled with innumerable dykes and sills of later date, which complicate and obscure the stratigraphy. Igneous rocks are estimated to cover quite half of the New Red Sandstone region.

These upper red rocks of Arran have been assigned at various times to all the geological systems from the Devonian to the Triassic. Sedgwick and Murchison,[1] in 1829, referred them correctly to the New Red Sandstone; and Sir Andrew Ramsay,[2] in 1841, adopted the same conclusion for most of the formation, although he referred a part to the Carboniferous. Bryce,[3] in 1859, thought that they were interstratified with the Carboniferous, and in the fourth edition of his 'Geology of Arran' identified them with the Calciferous Sandstones.[4] This view was shown to be impossible, at least for the Cock of Arran areas, when Wünsch and Thomson,[5] in 1874, found fossiliferous Carboniferous pebbles in the New Red breccias. They consequently relegated the formation to the Lower Permian. Subsequently Sir Archibald Geikie[6] referred these rocks to the Upper Old Red Sandstone; but, in 1897, he remarked the resemblance of the Brodick sandstones to those of Permian age on the mainland, and wrote that 'good reasons have been given for classing as Permian the bright red sandstone' of central and southern Arran.[7] This view was supported in 1897 by W. Gunn[8] for the same reason; and the rocks were represented as Permian on the first edition of the

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[1] *Trans. Geol. Soc. London*, Second Series, vol. iii., part i., 1829, pp, 32, 33 and section, Plate III.

[2] 'The Geology of the Island of Arran from Original Survey,' 1841, p. 77.

[3] 'The Geology of Clydesdale and Arran,' 1859, p. 70.

[4] 'The Geology of Arran,' 4th ed., 1872, p. 15.

[5] *Trans. Geol. Soc. Glasgow*,' vol. v., part ii., 1877, p. 313.

[6] 'Textbook of Geology,' 3rd ed., 1893, p. 801. *Also see* his 'New Geological Map of Scotland,' 1892.

[7] 'Ancient Volcanoes of Great Britain,' vol. ii., 1897, pp. 58, 418, 419.

[8] *Trans. Geol. Soc. Edinburgh*, vol. vii., part iii., 1897, p. 273.

Geological Survey map of South Arran (Sh. 13, issued 1898). On the second edition, 1902, the age was altered to Trias, in consequence of the discovery of Rhætic fossils in the Central Ring area, in beds associated with typical Triassic marls. In the Survey Memoir on North Arran, South Bute, and the Cumbraes (1903),[1] W. Gunn claimed that the discovery of the Rhætic fossils 'fixes pretty definitely the Triassic age of the upper division of the formation'; but both in the Memoir and the map the whole series is referred to the Trias. Jukes-Browne, in 1911, pointed out that, while the upper beds are Trias, the lower sandstones are probably Permian. This conclusion was fully substantiated by Prof. J. W. Gregory's detailed work of three years later,[2] and was reinforced by the discovery of a horizon of volcanic breccia within the Brodick Breccias in 1921.[3]

The New Red Sandstone is separated by a considerable unconformity from the underlying rocks. Near the Cock these strata rest upon the Lower Coal Measures, as they also do at Corrie and in the woods behind Brodick Castle. But towards the head of Benlister Glen they repose on the Corrie Limestone, hundreds of feet lower down in the Carboniferous formation, while on the west coast, to the north of the mouth of the Machrie Water, they lie directly on the Old Red Sandstone, all the rocks of the Carboniferous system having disappeared.

In the Memoir on Sheet 21 (p. 67) W. Gunn classified the rocks as follows :—

UPPER TRIAS—KEUPER ?	Red and mottled shales or marls with thin beds of white, yellow, or grey sandstone, and occasional thin bands of nodular limestone.
LOWER TRIAS. . .	4. Light-coloured and yellowish sandstones, sometimes red, with calcite in cavities. 3. Reddish sandstones with some conglomerates. 2. Conglomerates alternating with sandstones. 1. False-bedded red sandstones of Brodick and Corrie.

The classification adopted below is essentially that due to Prof. J. W. Gregory, amended and supplemented in several particulars :—

RHÆTIC .	Black shales and grey limestones (Ard Bheinn).
KEUPER .	7. *Levencorroch Marls and Cornstones.* Greenish-grey marls (Derenenach). Red shales with green layers and thin sandstones (Torr nan Uain), 60 feet. Marls and shales with layers of nodular and earthy limestones, and calcareous sandstones (Levencorroch), 200 feet.

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[1] p. 67.

[2] 'The Permian and Triassic Rocks of Arran,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 174–187. *Also see* G. W. Tyrrell, 'On the Boundary between the Red Rock Series near Whiting Bay and in the Sliddery Water, Arran,' *ibid.*, pp. 188–199.

[3] J. W. Gregory and G. W. Tyrrell, 'Excursion to Arran,' *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, p. 414.

BUNTER	6. *Auchenhew Sandstones and Shales.* Red and green shales with thin sandstones (Auchenhew), 350 feet. Sandstones (Auchenhew), 200 feet. Shales, with sharp-grained yellow and blue sandstones (Bennan), 150 feet.
	5. *Lag a' Bheith Marls and Cornstones.* Shales and marls with nodules and layers of cornstone; green and red calcareous and micaceous sandstones (Headwaters of Lag a' Bheith, Brodick; Loch na Leirg plateau).
PERMIAN	4. *Glen Dubh Sandstone.* White, yellow, and pink, massive, calcareous sandstone; thick-bedded, carious, but with smooth-weathering surfaces; blocky outcrops. A few lenticles of conglomerate (Southern slopes of Glen Dubh; Whiting Bay; Ballymichael Glen).
	3. *Lamlash and Machrie Sandstones.* Coarse red sandstone, slightly false-bedded, regularly thin-bedded at Machrie; occasional lenticles of conglomerate (Lag a' Bheith, lower part; Lamlash, Machrie Water, and Machrie Burn).
	2. *Brodick Breccia.* Coarse quartz- and quartzitic-breccia with horizons rich in basalt and agate pebbles; thick lenticles of red dune-bedded sandstone (Strathwhillan[1] shore, Brodick; Brodick Bay, southern part; Glen Dubh; Machrie).
	1. *Corrie Sandstone.* False-bedded, brick-red sandstone with rounded wind-worn grains (Cock of Arran; Corrie; Brodick Bay, north side).

Gunn estimated the thickness of the Lower Group or Permian at 2000 feet.

The diagrammatic section (Fig. 4) shows the general succession and arrangement of the various members of the New Red Sandstone formation in Arran.

THE CORRIE SANDSTONE AND BRODICK BRECCIA [2]

These groups are treated together as there is reason to believe that they form but one stratigraphical unit. In his MS. notes for Sheet 13, Mr. Gunn stated that in the southern half of Arran 'the lower false-bedded sandstone, and the bands of conglomerate, do not form separate subdivisions, the conglomerates often occurring at the base, and on various other horizons.' This is in entire conformity with the view that the formation represents a desert accumulation, a great mound of dune-bedded desert sand (the Corrie Sandstone) being deposited in one place, whilst desert screes (the Brodick Breccia) were being piled up elsewhere.

The Brodick Breccia is divisible into three horizons which have been found to be remarkably persistent. Its basal parts consist mainly of vein-quartz, quartzite, and schists, of Highland provenance, in a matrix of red sand; and fragments of this nature are found, although in relatively smaller quantity, throughout the entire thickness of the bed. In the central horizons, however, a great number of basalt pebbles come in, sometimes in such quantity and of such sizes as to suggest the near proximity of the distributing volcanoes. These basalts are of well-known Carboniferous and Permian types ; the larger masses are generally angular, but a few are sub-rounded and suggest volcanic bombs. The smaller sand grains are usually wind rounded. Basalt pebbles appear in diminishing numbers up to the top of the breccia, but here numerous white-weathering agate pebbles occur, and are everywhere characteristic of the uppermost horizons. G.W.T.

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[1] Strathwhellan on One-inch Geological Map (1910).

[2] Much of the new field-work on the New Red Sandstone in Arran has been done in conjunction with Mr. B. H. Barrett, M.A., B.Sc.

1. The lowest subdivision is well exposed along the shore between Corrie and Brodick Castle, and consists of extremely false-bedded, bright-red sandstones, traversed in many places by ridges formed of hardened joints and crushes, and in others full of ramifying hardened veins which cause the rock to weather with a honeycomb structure. Some of the crushes are certainly faults, but the rock is so uniform in texture generally that the amount of throw is not discernible. Numerous basic dykes cross the foreshore in various directions and discharge the red colour of the rock, making it white or yellow, and hardening it. Some of the ridges are probably in the line of dykes which end at the surface, and some may be due to dykes which have not reached the present surface. The false-bedding conveys a very exaggerated idea of the real thickness of the series. Fine sections in the old sea-cliffs, and in caves, show that the true dip towards the south-east is not more, generally, than 10° to 15°, while the false-bedding has an inclination of twice as much, and is, besides, very variable in direction. The great cliff on the north side of Maol Donn, which is formed of this sandstone, shows a similar gentle inclination of the beds. This great scarp is largely due to an extensive slip, the material from which covers several acres to the northward. There are large quarries in this sandstone at Corrie and in Brodick wood at the back of the school. From the Corrie quarries much stone was shipped to

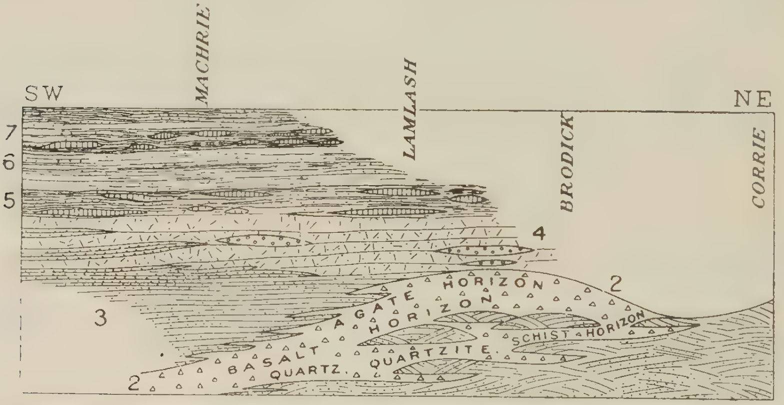

Fig. 4.—*Diagrammatic section showing the general structure and arrangement of the New Red Sandstone formations* (*c.f.* pp. 76–77)

Ayrshire and various parts for building purposes. This sandstone forms the ridge on the north side of Glen Cloy, where both the true and the false bedding dip to the southward or south-east at a high angle, as they do also to the west of the old Brodick Pier near the Castle. The boundary between this rock and the underlying Carboniferous series may be observed on the shore about 200 yards south of the Corrie Hotel, and it crosses the Rosa Burn a little below the bridge. W.G.

Mr. E. B. Bailey has recently described the junction between the Upper Carboniferous and the New Red Sandstone on the shore about 200 yards south of Corrie Hotel.[1] The junction plane is parallel to the general stratification of the underlying Carboniferous and is marked by scattered, minute pebbles of vein-quartz and iron pan, which, mixed with many rounded quartz grains, constitutes an attenuated representative of a basal conglomerate.

The alternating breccias, conglomerates, and sandstones of the south side of Brodick Bay overlie the false-bedded sandstones just described, and the conglomerates of this division are so like in character to the Upper Old Red conglomerates north of Corrie that several observers have classed them with the older formation. They are largely made up of debris of the metamorphic rocks, such as pieces of vein-quartz and angular fragments of schist, with occasional pebbles of quartzite, like those characteristic of the Lower Old Red conglomerates. This subdivision strikes westward up Glen Cloy and forms the ridge between Glen Dubh and Glen Ormidale.

The section in Glen Dubh is noteworthy as containing the best exposure so far known of a horizon of volcanic breccia or conglomerate, the stratigraphical position of which is believed to be near the middle of the Brodick Breccia. The exact locality is the Glen Dubh Water, about 250 yards above its confluence with the Glen Ormidale Water, and at the point where it receives its first tributary from the east above the confluence. Just at the junction with the tributary there is a small waterfall which is caused by the band of volcanic breccia. The best exposure, however, is about 20 yards farther down the stream, where the breccia forms a ledge on the south bank. An east-north-east fault, occupied by a crinanite dyke, and with a downthrow to the south of about 12 feet, separates the two main exposures (Fig. 5). The section is greatly complicated by numerous basalt dykes and a felsite-pitchstone sill.

Some bands of the breccia are bluish in colour; others are stained dull red with hæmatite. The fragments are basaltic, dark, amygdaloidal, and iron-stained, closely resembling certain Carboniferous and Permian types. The matrix is partly sandy, and partly comminuted volcanic debris. Both below and above the breccia band, which is from 8 to 12 feet thick, the sandstones for some distance are dark red in colour and very basic and tuffaceous. The dip is about 20° to the S.S.W. On the south side of the stream, the breccia band is first overlain by well-bedded, dark-red, tuffaceous sandstones and sandy shale, and finally by a thick band of quartz-conglomerate, which is also seen above the waterfall section. The dark-red tuffaceous sandstones are visible in several of the tributary burns which enter the Glen Cloy Water from the east near Kilmichael, and it has also been found by Mr. W. J. McCallien, in the Lag a' Bheith, about a quarter of a mile south of Brodick Hotel.

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[1] 'Subterranean Penetration by a Desert Climate,' *Geol. Mag.*, vol. lxiii., 1926, pp. 276–280.

Sgiath Bhàn, the hill rising between Glen Dubh and Glen Ormidale, consists mainly of the Brodick Breccias, with a capping of the overlying Glen Dubh Sandstones. At the base of the hill, on the north-east side, there are sparsely-pebbly, dark-red sandstones occasionally enclosing large angular slabs of a fine-grained red, argillaceous sandstone. Higher up come dark purplish and reddish tuffaceous greywacke types, very hard and compact. On these there rest quartz-conglomerate and breccia interbedded with red sandstone and containing agate pebbles. Finally, at the top of the hill, the whitish and rusty-speckled Glen Dubh Sandstone appears.

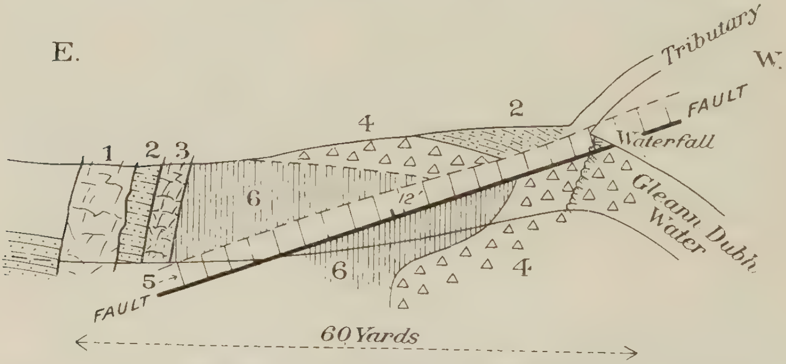

FIG. 5.—*Map of exposures in Gleann (or Glen) Dubh Water, one-eighth of a mile above confluence with Glen Ormidale.*

1. *Porphyritic basalt dyke*; 2. *New Red Sandstone*; 3. *Dyke of dense basalt*; 4. *New Red Sandstone volcanic breccia*; 5. *Crinanite dyke*; 6. *Felsite sill.*

Near the heads of Glen Dubh and Glen Ormidale the Brodick Breccia, along with the false-bedded sandstone below, has been much altered, being often converted to a white quartzite by contact with the intrusive igneous masses there.

On the shore at Springbank, near the Brodick Hotel, the formation is very much broken in two small areas, which were supposed to represent volcanic vents. The larger of these is about 150 feet in diameter and the smaller about 50 feet, though in neither case can the whole circumference of the mass be seen. The smaller is about 100 yards west of the hotel grounds, and the larger is some 150 yards farther west, and the breccia which composes both is entirely made up of fragments of the surrounding strata. The origin of these features is much in doubt. They are hardly volcanic vents in the accepted sense of the term, for there is not the slightest

trace of any volcanic material. It may, perhaps, be hazarded that they possibly represent the effects of the explosive emission of gases from small, subjacent, hidden, Kainozoic intrusions, probably dykes.
G.W.T.

In this subdivision there is not much false-bedding apparent, and the rocks at Springbank dip southward at about 15°. East of the pier numerous faults as well as dykes cross the outcrop, and the red conglomerate is seen to overlie false-bedded red sandstone of the same type as that on the north side of the bay. One of these faults ranging N. 25° E., which is 50 yards east of the pier, brings up the lower sandstones against the conglomerate. The sandstone occupies the foreshore for 300 yards eastwards when it is cut off by a fault, coincident with a dyke ranging N. 25° W., which throws down the conglomerate again on the east. For about 500 yards eastward from this point we see nothing but conglomerate on the foreshore till a north-west running fault, with a downthrow south-west, again brings the lower sandstone into view. This is continued for 300 yards farther in the most easterly part, being overlain by conglomerate, when a fault ranging N. 25° E. causes the whole of the foreshore to be occupied by conglomerate, but this is only for a distance of 30 to 40 yards, when a powerful fault, N. 30° E., brings up the lower sandstones, which occupy not only the shore for a long distance but the cliffs also, which are much increased in height. Hitherto along this shore the conglomerate series could be seen either on the shore or on the boundary cliffs, but the effect of this large fault, which must have a downthrow west of several hundred feet, is to raise the conglomerate a long way above the top of the crags at this point, and it does not appear again on the shore till the southerly dip causes it gradually to descend and occupy the shore about Corrygills Point. Along this half mile of shore and in the cliffs bounding the raised beach the false-bedded lower sandstones are well exposed, with the same curious spires and ridges which we found characterizing them on the north side of Brodick Bay. The southerly dip is everywhere nearly the same in amount, ranging between 10° and 20°, but as we proceed the direction gradually changes till, in the alternating conglomerates and sandstones on either side of Corrygills Point, it is nearly S.S.W.
W.G.

Re-examination of the Strathwhillan shore, east of Brodick Pier, by Mr. B. H. Barrett and the present writer, showed that, while there are several small faults, there are no traces of the large faults necessitated by Mr. W. Gunn's interpretation of the section as detailed above. His explanation seems to have been called for because the great masses of red, dune-bedded sandstone in the cliffs were regarded as upthrown blocks of the underlying Corrie Sandstone. These masses, however, can be shown to be overlain and underlain by Brodick Breccia, and are best interpreted as fossil dunes, or groups of dunes, against and around which the breccias were banked up and interbedded.

At Brodick Pier is typical breccia; immediately to the east is a stretch of red, ribbed sandstone devoid of pebbles, similar to the Corrie Sandstone. Three hundred yards east of the pier the sandstone is succeeded abruptly by breccia on the eastern side of a wall-like edge probably due to a dyke. As the sandstone near by is much disturbed and brecciated, this edge is no doubt the line of a small fault.

The basaltic horizon in the Brodick Breccia is well exposed in the cliff bordering the 10-foot raised beach at a point half a mile east of the pier, and one-sixth of a mile west of a small lagoon on the shore. There is here a considerable thickness of loose, crumbling breccia, consisting of rounded and subangular pebbles of red-speckled vesicular basalts. Some of the larger cobbles resemble volcanic bombs. Associated with the coarse breccias are dark-red tuffaceous sandstones, and hard ribs of dark-red shaly sandstones. The cliff shows beds of basaltic fragments intermingled with sandstone, exactly as in the Ballochmyle section above the lavas of the Mauchline (Ayrshire) basin.

A fault along which runs a basalt dyke terminates this exposure on the east, and it is succeeded in this direction by apparently upfaulted quartz-breccia. Then, wedging out abruptly amongst the breccias, there occurs an enormous lenticle of red, dune-bedded sandstone, without a band of breccia from top to bottom. This forms cliffs 150 to 200 feet in height, and red sandstone also forms the shore-section at this point. It is suggested that this mass of sandstone represents the remains of a group of dunes. Near Corrygills Point bands of breccia come in, and are seen to be interbedded with red sandstone. The overlying red sandstone is thin-bedded and dips at 25° to the south-east.

In the raised-beach cliff at the back of the big granite erratic near Corrygills Point, quartz-breccia overlies the thinning south-eastern termination of the red sandstone lenticle described above, and on the shore quartz-breccia can also be seen to underlie it. One of the best exposures of the agate-bearing horizon of the Brodick Breccia is found on the shore a quarter to half a mile south-east of the mouth of the Corrygills Burn. Fine agates, weathered out from the breccias and the intercalated pebbly sandstones, may be gathered on the foreshore.

The Corrygills Burn provides a slowly-ascending section in the beds at the top of, and immediately above, the Brodick Breccia. Near its mouth there is quartz-breccia interbedded with red sandstone; and thick-bedded red sandstones with occasional intercalations of breccia, and one ledge of very coarse white sandstone, occupy the burn for a distance of one-third of a mile from its mouth. West of this point the flaggy and shaly red sandstones of the Lamlash–Machrie group appear, some beds showing occasional flakes of white mica. Rocks of this type also occur by the roadside near Corrygills Bridge. The dip is mainly S.S.W. at angles from 15° to 25°.

The Brodick Breccias are well exposed in the middle part of the Benlister Burn where the conglomerates form occasional cascades. This series also occupies a strip of ground to the northward, west of Brisderg, which is bounded by two large faults The beds in this strip dip to the south-west, and their termination north is in the fine scar of Creag nam Fitheach, on the south side of Glen Dubh.

On the north-east the Creag nam Fitheach section is bounded by a fault trending north-west, which brings the Glen Dubh Sandstone down against the Brodick Breccias. The crags are intersected by a number of dykes which, in some cases, run along small faults. In spite of this disturbance it is clear that Creag nam Fitheach consists mainly of beds belonging to the upper part of the Brodick Breccias. They consist of dark-red streaky basic sandstones with clay galls, interbedded with quartz pebble-conglomerates and quartz-breccias, in which no basalt pebbles were found. There are also some hard, white and green, quartzitic sandstones, above which is a considerable thickness of red, false-bedded sandstone with inconstant pebble beds, and some coarse breccia bands. Agates occur in the pebble beds but are not abundant. Shaly beds in the red sandstones show good suncracks and are occasionally ripple-marked. The sandstones are also ripple-marked and contain mud flakes. These beds are probably on the Lamlash–Machrie Sandstone horizon.

Three good sections of the basement beds of the New Red Sandstone occur in the Machrie district. The evidence shows that they are here considerably thinner than on the eastern side of the island. A junction between the New Red Sandstone and the Old Red Sandstone can be closely located in Machrie Bay, on the shore about 200 yards north of the Post Office. There is nothing representative of the Corrie Sandstone, and the Brodick Breccia rests conformably on the Upper Old Red Sandstone (?), both series dipping S.S.W. at 50°. The Brodick Breccia has a reddish matrix containing scattered quartz and quartzite pebbles which are, however, thickly aggregated in some beds, with occasional pebbles of red-speckled basalts and white-weathering agates. It can be easily distinguished from the Upper Old Red Sandstone (?), which has a dark greenish-grey matrix, contains quartz, quartzite, and schist fragments, but no basalt or agate, and has suffered considerable epidotization. There is a transitional zone a few feet in thickness between the two rock types.

In the Machrie Burn 1 mile east-south-east of the exposures on the shore of Machrie Bay, and half a mile north-north-east of Machrie Farm, unquestionable Old Red Sandstone conglomerate, with rounded cobbles and boulders of quartz and quartzite, and with inconstant streaks of sandstone, occurs at a sharp bend in the stream. It strikes 37° W. of N., with dip 40° to vertical. A few yards down stream a bright-red sandstone appears, which, in a short distance, contains increasing interbeds of quartz-schist-breccias. A quarter of a mile north of Machrie Farm agates occur in abundance. The dip is 65° to the south ; hence there is a certain discordance with the Old Red Sandstone. At this point Mr. Gunn drew a doubtful boundary between the New Red Sandstone and the Old Red Sandstone (One-inch Geol. Surv. Map of Arran, 1910), but the actual boundary is 200 to 300 yards farther north as determined by the change in the lithology of the rocks. There is little trace of the basaltic horizon in this section, only a few streaks and thin beds of the typical dark-red tuffaceous sandstones being found. The section passes up into the thin-bedded red sandstones of the Lamlash–Machrie group (p. 93). The estimated thickness of the basal subdivision in the Machrie Burn is 600 feet.

In the Machrie Water section, 2 miles east-south-east of the Machrie Burn section, the New Red Sandstones are first encountered below the deer fence at the north-eastern corner of Machrie Wood, half a mile north-west of Derenenach. Above this point the river bed is occupied by the red and purple sandstones, and coarse quartz-conglomerates of the Old Red Sandstone. The New Red Sandstone begins with a few feet of bright-red, round-grained sandstone, dipping at 30° in a direction 25° W. of S., probably an attenuated representative of the Corrie Sandstone horizon. There is no visible junction with the Old Red Sandstone. This is followed by the usual breccia with quartz, quartzite, and schist fragments, and interbeds of the dark-red tuffaceous sandstones of the basaltic horizon. Dune-bedding is prominent in some of the layers. Within the wood coarse sandstones and fine conglomerates with small basalt and agate pebbles, clay galls, and polished and rounded quartz grains, are abundant. Some of the layers are very rich in agate and basalt ; others, on the other hand, appear to be devoid of them. These beds are followed by the thin-bedded shaly sandstones of the Lamlash–Machrie group. The thickness of the Corrie Sandstone and Brodick Breccia in this section is estimated at 600 feet, the same as in the Machrie Burn. G.W.T.

The detached outlier of New Red Sandstone at the Cock of Arran, in the north part of the island, contains false-bedded, bright-red sandstone, like that of Corrie, and beds of conglomerate which mainly overlie the sandstone, though conglomerates occur in the lowest 40 feet of the sandstone itself. The mass of conglomerate is like that on the south side of Brodick Bay, and probably on the same horizon, so that we have in this small area representatives of the lower two subdivisions of the formation, with a total thickness of not less than 1200 feet. The beds generally dip northward and toward the sea, so that several landslips on a large scale have occurred, and the hillsides show gaping fissures.

In the lowest part of the New Red Sandstone which immediately overlies the Carboniferous formation in the northern part of Arran, there are bands of conglomerate which contain pebbles of Carboniferous limestone from which several derived fossils have been obtained by the Geological Survey. Rather more than a quarter of a mile north-west of this spot, and about 100 yards east of the Cock of Arran, is another locality where derived fossils may be collected. There occurs a very irregular pebbly band, which appears to have accumulated in a hollow of the sandstone during the process of rock formation. It contains, among others, large blocks of trap and white quartz, etc., and from it the following collection was made :—

Coral, indet., rugose
Lithostrotion
Crinoid ossicles
Rhabdomeson or Rhombopora
Spiriferid
? Nucula gibbosa *Flem.*
? N. oblonga *M'Coy*
Protoschizodus axiniformis (*Portl.*)
Bucanopsis.

It was probably in the first-mentioned locality that derived Carboniferous fossils were obtained by Messrs. James Thomson and E. A. Wünsch, as reported in the *Trans. Geol. Soc. Glasgow*, vol. v., p. 313 (1874), and described in vol. xi. of the same *Transactions*, p. 30 (1897). W.G.

LAMLASH–MACHRIE SANDSTONE, AND GLEN DUBH SANDSTONE

The Lamlash–Machrie Sandstone and the Glen Dubh Sandstone constitute together the upper part of the lower division of the New Red Sandstone in Arran. With the underlying Brodick Breccias (with which these sandstones appear to interdigitate) and the Corrie Sandstone, they have been regarded by Prof. J. W. Gregory as belonging to the Permian system. In the neighbourhood of Brodick the Lamlash–Machrie Sandstone and the Glen Dubh Sandstone are clearly separable ; but in other localities their separation is not so easily effected, for bands of whitish calcareous sandstone of the same character as the Glen Dubh Sandstone are found intercalated in the Lamlash–Machrie Sandstones in increasing numbers towards the top of that group.

The Lamlash–Machrie Sandstone consists of dull-red, soft, thin-bedded sandstones, occasionally micaceous and shaly, often with scattered pebbles and bands of breccia, and with one or two lenticles of conglomerate made up of rounded water-worn pebbles and cobbles. The Glen Dubh Sandstone is a massive, white, yellow, or pink, rusty-speckled sandstone, often coarse, and usually with some calcareous cement. The outcrops weather in blocky fashion, and the rock, while often pitted with large holes, nevertheless preserves a smooth, glazed surface. The red sandstones occupy most of the lower ground from Corrygills, through Lamlash Bay, to Whiting Bay. They are also prominent in sections in the Machrie district. The best and most typical exposures of the Glen Dubh Sandstone are on the high moors between Glen Dubh and the Benlister Burn, and on the high ground west of Lamlash and Whiting Bay. In the west the Clauchan and Ballymichael Glens provide exposures of rocks on this horizon. The Tormore shore-section and a considerable area to the west of Tighvein, may also belong to this subdivision. G.W.T.

Along the South Corrygills shore the alternating conglomerates and sandstones pass gradually up into the beds of the Lamlash–Machrie subdivision, which consists almost entirely of red sandstones, moderately coarse, with only occasional pebbly bands, and with comparatively little false-bedding. The dip inclines more and mor to the west and generally increases in amount, so that in place along the shore east of the Clauchland Hills the dip is as high as 30° or 40° and the strike is parallel to the shore. Near Clauchlands Point the dip is in one place as much as 60°, but this high dip is probably the effect of the intrusion of the great sill of dolerite there. On the south side of the Clauchland Hills the inclination of the beds is much more gentle, generally not more than 10°, and nearly coinciding with the slope of the ground to S.S.E. There are numerous sections in the small streams here, and along the northern shore of Lamlash Bay.

The beds of this subdivision occupy nearly all the area between Lamlash and Glen Cloy, and there is a fairly continuous exposure of them in the Birch Burn (Lag a' Bheith). They also form a marked feature above the wood to the south-east of Bruce's Castle in Glen Dubh,[1] and it is probably the higher beds of this series that appear beneath the thick sills of felsite along the west side and at the north end of Holy Island. W.G.

On the south side of Glen Dubh there are a long scarp and terrace descending eastward from The Sheans, which mark the outcrop of a thick band of rusty-spotted, white, felspathic sandstone. This bed weathers into blocky outcrops, and has irregular, carious surfaces, although some bands are well bedded and slabby. The dip is 10° to the S.S.E. The same sandstone is again seen in a bouldery outcrop east of the Brodick–Lamlash Road, north of the Clauchland sill.

The red sandstones of the Lamlash–Machrie series are well exposed at Gortonallister, between Lamlash and Whiting Bay. The rock is a thick, massive, fine-grained, red sandstone, which rests on a softer, more argillaceous sandstone. It has no conspicuous false-bedding, and no interstratified conglomerate bands. The Lag a' Bheith sections, between Lamlash and Brodick, are mainly in the same series. G.W.T.

By the roadside, and in the path near Cordon (Lamlash) some shale bands occur in the red sandstone. Along the coast to the east of Gortonallister the whitish and yellow sandstone is slightly veined parallel to the shore, and forms spiry projections recalling the sandstone of the lowest subdivision north of Brodick. About Fairiebank soft red sandstone, yellow sandstone, and white sandstone, are successively encountered in an eastward direction.

South of Kingscross Point the sandstone is altered by contact with the crinanite sill, and in several places the white and yellow sandstones weather with carious surfaces. In the neighbourhood of Whiting Bay the sandstone is usually soft, red, and often flaggy, and contains occasional bands of red shale. Near the numerous dykes the colour is often discharged, and the sandstones become white and quartzitic.

Sandstone belonging to this subdivision is found in the southern part of Holy Island. On the west coast at St. Molio's Cave massive red sandstone appears, which rises to about 200 feet above sea-level, and must have as great a thickness. To the south this sandstone is covered by screes from the great sill above, but appears again at the Sheep Cave, where it is still massive and partly of a whitish colour. Hardened and altered white sandstone and conglomerate appear, dipping to the south-east, between two sheets of crinanite to the north of the lighthouse. These igneous masses occupy the southern shore, but rise up along the eastern coast, and the sandstone appears below, with a general dip to N.N.W. of from 10° to 20°. In places parts of the sandstone are caught up in the sill and much altered. Beyond this the igneous rock again occupies the shore. W.G. (MS.)

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[1] This is the scarp of Glen Dubh Sandstone referred to below.

North of the eastern lighthouse the coast is bordered by a fine cliff of bright-red sandstone, worn in curious deep hollows and niches like gigantic honeycomb weathering. It exhibits marked dune-bedding. A 10-foot band of yellow sandstone appears at the north end of the cliff. The whole section shows an apparent shallow synclinal structure. G.W.T.

Inland from Lamlash good sections are visible in Monamore Glen and its tributaries. The higher beds, consisting of yellow and white sandstones [the Glen Dubh Sandstone ?] are exposed in the burn west of Sguiler, and in all the burns north-east of Urie Loch. The lower beds near the junction of these burns with the Monamore Water, and on the sides of Monamore Glen, are more often of a red colour, are more false-bedded, and sometimes contain pebbles [the Lamlash–Machrie Sandstone]. Near Monamore Flour Mill are two good-sized quarries where the sandstone is wrought for building purposes. In each of the quarries there are basaltic dykes, and the sandstone is intersected by faults. In the quarry immediately south of the Mill there are exposed about 25 feet of thick-bedded, reddish sandstone, with partings of thinner-bedded stone, some of which is very micaceous. Below is thick, whitish sandstone, of which 10 feet or more is visible on the west side of a fault which ranges north-west and appears to throw down about 10 feet on the east side. The sandstone of the more easterly quarry is pierced by two north-west dykes, and crossed by a fault running east-south-east which hades to the south. W.G. (MS.)

In the stretch of country to the west of Whiting Bay the boundary between the lower and upper divisions of the New Red Sandstone occurs, as far as can be ascertained, a little below the base of the Borrach felsite mass. In Glen Ashdale the main dolerite sill (which gives rise to the waterfall) has been intruded near the junction of the two series; and to the south a thin lower member of the same sill complex is taken as the mappable horizon which marks the boundary.

A typical section is given by the stream ('Burn B') which drains into Glen Ashdale from the north-west about one-third of a mile east of Cnoc Mòr (Plate II). Starting from the path on the north side of Glenashdale Wood, a glaciated exposure shows fine-grained 'blue basalt' weathering in rounded masses with exfoliation. The bed of the stream is occupied for some distance by a dyke of porphyritic basalt. The sill is overlain by soft whitish and buff thin-bedded sandstones—probably red sandstone with its colour discharged by the igneous contact. In these rocks there is a horizon characterized by chocolate-coloured, ferriferous and micaceous sandstones, a band of which forms a small fall. Above these there are a few hard quartzitic bands, which weather in the stream-bed with smooth surfaces. Before the base of a second basaltic sill is reached, the sandstones again become soft and argillaceous, and begin to be intercalated with shales and marls. Above the second sill the sediments become increasingly marly, but still contain a few bands of harder red sandstone. Typical Triassic marls and shales, however, form the whole of the section before the third and last sill is reached (Fig. 6). The beds are practically horizontal. This is perhaps the best section for showing that the transition between the upper and lower divisions of the New Red Sandstone is perfectly gradual, and that there is no recognizable discordance. The lower sandstones become softer and more argillaceous on being traced upward, and are intercalated with bands of shale and marl in increasing numbers until the latter constitute the whole of the sedimentary succession. Similar sections are to be seen in the Allt Garbh, Borrach, 1½ miles west of Whiting Bay Pier, and in several other burns tributary to Glen Ashdale.

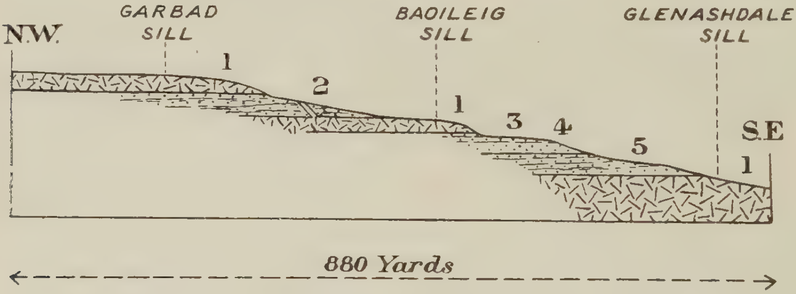

FIG. 6.—*Section along Burn B., one-third of a mile east of Cnoc Mòr, north of Glenashdale Wood.*

1. *Quartz-dolerite and craignurite sills ;* 2. *Shales and marls ;* 3. *Quartzitic sandstone ;* 4. *Chocolate-coloured ferriferous sandstone ;* 5. *Thin-bedded red sandstone.*

There is an excellent coastal section in the upper sandstones along the coast to the south of Whiting Bay, from Creag Dubh to Dippin. Creag Dubh consists of a sill of fine-grained dolerite resting upon and overlain by sandstone dipping 22° due west. The section from here to Largybeg Point is in thin-bedded red sandstone, which contains an occasional quartz-pebble and local sprinklings of fragments of green and brown shale. The dip is 20° to 30° slightly S. of W., and the strike a little east of south, so that higher beds are slowly exposed as the observer walks southward along the coast. Some of the sandstones are coarser and grittier than others, and many have a cement of whitish, decomposed, felspathic material. Rocks of this character are to be seen in the quarry east of Largymore, and Prof. P. G. H. Boswell has suggested that they would provide good moulding sand.[1]

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[1] 'A Memoir on British Resources of Refractory Sands for Furnace and Foundry Purposes,' Part i., London, 1918, p. 169.

Other sandstones along this shore have a calcareous or dolomitic cement, and in these rocks occurs a peculiar carious weathering, which may be seen at many places, notably at Largybeg. This feature is often especially well developed where the sandstone is hardened by igneous action. The hollowing is sometimes replaced by a nodular weathering, resulting frequently in clavate or mushroom-shaped projections. This weathering is due to an irregular distribution of the calcareous cement, or to variations in its composition, rendering it more liable to solution in some places than in others. A related phenomenon has been noted by Gunn about 200 yards south of Largybeg Point, where there is a bed of red sandstone 6 inches thick, which contains numerous nests of calcite in cavities on its sloping surface. They are of all shapes and sizes up to as much as 6 inches in diameter, and one lenticle measured more than 12 inches. These sandstones represent the Glen Dubh Sandstone horizon in this locality.

A thin band of bluish shale appears in the small cove just north of Largybeg Point. At the Point itself the section is diversified by a 15-foot sill of basalt, and by a bed of conglomerate 6½ feet thick. The full section across the Point from south-west to north-east in descending order, is as follows :—

	Ft.
(*a*) Thin-bedded red sandstone	42
(*b*) Basalt sill	15
(*c*) White gritty sandstone, with line of local unconformity and rock-arch	33
(*d*) Coarse grit with bands of conglomerate	9
(*e*) Conglomerate	6½
(*f*) Carious white sandstone	9

The last bed abuts against a thick felsite dyke hading 45° E., beyond which is the sea. The sedimentary rocks are intersected by three basalt dykes, one of which forms an outstanding wall, and the others trench-like depressions. A curious rock-arch, excavated in bed (*c*), now stands on the 10-foot raised beach well above high-water mark. The section is shown in detail in Fig. 7.

To the south of Largybeg Point the dip of the strata becomes nearly parallel to the shore, and averages 10° to 15° to the south-west. For a hundred yards the section is then covered by shingle, broken only by one small outcrop of sandstone maintaining the same dip. Beyond the shingle comes the outcrop of a small basalt sill, which has protected the strata beneath it. The latter are sandy marls, interbedded with sandstone, and are bent into a flat anticline, whose northern limb dips to the north, and is opposed to the dip of the sandstone of Largybeg Point. The slight flexure and change in direction of dip is probably due to the influence of the little sill, but it is curious that a change of dip should come close to the point where, according to the One-inch Map, the junction of the sandstone and marl divisions takes place.

From this point until the escarpment of the great Dippin sill of teschenite or crinanite sweeps down to the shore, the rocks are covered by shingle. The lower contact of the sill is exposed at the north end of the cliff, and the igneous rock rests upon hardened and burnt shale, dipping about 10° to the north. The south-westerly dip is resumed, however, to the west of Dippin at Torran Clachach, and to the south-west of the sill at Kildonan. It is probable therefore that the small flexure at Dippin is local and due to igneous intrusion.

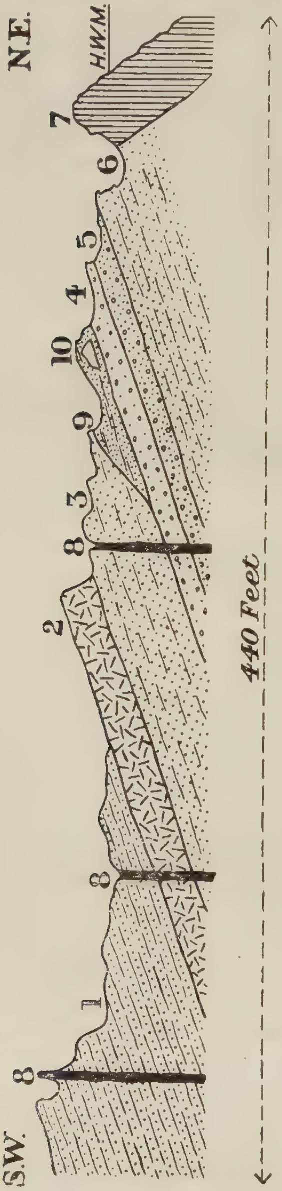

FIG. 57.—*Section across Largybeg Point.*

1. *Thin-bedded red sandstone*; 2. *Quartz-dolerite sill*; 3. *White sandstone*; 4. *Coarse grit with bands of conglomerate*; 5. *Conglomerate*; 6. *Carious white sandstone*; 7. *Thick dyke of craignurite-felsite*; 8. *Basalt dykes*; 9. *Line of local erosion*; 10. *Rock-arch on raised beach.*

It is unfortunate that the critical junction in this section, which occurs a little to the south of Largybeg Point, should be so largely obscured, but what evidence there is available goes to show that the transition between the two divisions of the New Red Sandstone is gradual, and that there is no marked discordance.

G.W.T.

There is a wide spread of rocks belonging to the upper part of the lower division of the New Red Sandstone in the interior region of the southern half of the island, between Tighvein and Tormusk, a region centrally drained by the upper part of the Sliddery Water. This area is much cut up and obscured by the Kainozoic igneous intrusions. There are good sections in all four of the branch streams which run southward into the Sliddery Water above Glenscorrodale, the two best being those exposed in the burns on either side of the isolated hill called Cnoc na Dail. The most easterly stream, which is called the Allt Mòr, exposes a considerable thickness of rock, much of the sandstone being coarse and pebbly, passing into a conglomerate in places, especially near the junction of the two streams south-east of Cnoc a' Chapuill, where the base of the New Red Sandstone rests on the Carboniferous strata. The beds appear to dip to the west of south at angles of 10° to 20°; and this direction of dip prevails in the stream west of Cnoc na Dail, it being south-south-west in the upper part of the section, and south-west in the lower part, the amount being between 20° and 25°. In the higher part of the stream the sandstone is reddish; lower down it varies from yellow to red, and is very false-bedded, and is coarse and pebbly in places. Occasionally a whitish colour prevails, and in the lower part of the burn the rock becomes flaggy, and includes a shale band 10 inches in thickness.

In the next stream to the west the dip is 20° to 30° and nearly always to the south. The lower part of this section shows very false-bedded white and quartzose sandstone. Reddish, yellow, and white sandstones with the same general dip as before are exposed in places in the next stream above Glenscorrodale. Sometimes the rock is flaggy and fine grained, in places being almost shaly; but in general it is thick bedded and occasionally hard and quartzose. North of the igneous mass of Tormusk, where the same general dip prevails, the sandstone is more often of a red colour.

The main stream of the Sliddery Water gives few and poor sections of the beds under description. Its most easterly exposure is close up against the basic igneous mass which bounds the Upper Carboniferous of its southern headwater. The sandstone here dips west, and is much altered, being hard, white, and quartzitic. Many of the branch streams entering from the east give fairly good and continuous sections, which are intruded by an immense number of large and small igneous masses. The upper part of the Allt na Tuaidh, which joins the Sliddery Water opposite Glenscorrodale, shows soft red or yellow sandstone dipping gently W. or W.S.W. Rocks of much the same character crop out in both branches of the head of the Cloined Burn, and near the head of the Kilmory Water to the west and south-west of Tighvein. The dip varies between W.S.W. and S.W., and the amount is usually from 10° to 20°. W.G. (MS.)

In the Sliddery Water, 200 yards above Glenrie Bridge, a junction of pink banded felsite is seen against sedimentaries. The nearly horizontal joint-planes of the igneous rock curve up until they become nearly vertical at the junction, which may be a fault-plane (Fig. 29). The sediments here consist of chocolate, white, and reddish sandstones, interbedded with a little true marl, and other marls of sandier type.

At the right-angle turn in the stream, 200 yards higher up, the sediments are rather hard, whitish, or yellow sandstones dipping downstream at 10° to 20° to the south. They are cut by two north to south dykes, and are not interbedded with shaly material. These sandstones weather with a rough but hardly carious surface. They are in beds about 1 foot thick, and although they are sometimes thinner bedded they do not pass into shaly types. These strata are taken to belong to the lower sandstone division, and the exposure containing marls, at the felsite junction, as belonging to the upper marly division. The junction in this case is occupied by a felsite-pitchstone sill, and should be drawn about a quarter of a mile farther to the north than it is represented on the One-inch Geological Survey Map.

The Burican Section.—The section commences at the forking of the Allt Burican about three-quarters of a mile above Burican. Nothing can here be seen of the fault, which, according to the

Geological Survey map, crosses the stream near the fork. At a right-angle bend below the fork are exposures of thin-bedded and false-bedded red sandstone, dipping due west at about 10°. A small gorge along the strike occurs below this, and is crossed by two thin basalt dykes, causing a cascade.

At the 'hairpin bend' lower down, red and green sandy shales and marls are seen interbedded with sandstone. These rocks appear at intervals in the stream-section down to nearly opposite Burican. Here, however, after a blank interval, a whitish, thick-bedded sandstone occurs dipping 20° to 30° downstream. This looks very much like the white rough-weathering sandstone of the Sliddery Water. Between the ford and the footbridge opposite Burican there are bands of red sandy marls interbedded with white and red sandstone, the latter having distinct carious and nodular weathering. Below the footbridge occur typical soft, unctuous red marls, 2 feet thick, interbedded with red sandstone in a small exposure. Below this the section for a long way is in pink felsite.

Near the 254 feet O.D., about 250 yards above Glenrie Bridge, the only indication of a fault is seen in an exposure of red marls, interbedded with carious sandstone, with nearly vertical dip. Below this the section passes again into felsite, which continues to the junction with the Sliddery Water. According to the Survey map, the Burican Burn runs along the line of a fault separating the lower sandstones from the upper marly series, but of a fault direct evidence was obtained at one point only, in spite of good exposures. It is more probable therefore that the fault crosses the stream at an angle.

In the west, rocks belonging to the upper division of the lower part of the New Red Sandstone occur in the Clauchan and Ballymichael Glens, on the coast at Machrie Bay and Tormore, in the Machrie Burn, and in the Machrie Water. A strip of ground lying between two N.N.W. faults, and extending across the Ballymichael and Clauchan Glens in the same direction, is assigned to the above division. Prof. J. W. Gregory has described a good section in the burn about one-fifth of a mile south of Ballymichael Glen, near Ballymichael. Green-spotted red shales with thin sandstone bars, and sharp-grained greenish sandstones, are seen at levels below 300 feet, dipping west at 20°; but the carious sandstones which mark the top of the Permian begin to appear on the moor to the east of a stone wall and beyond a felsite dyke at the height of about 450 feet. The junction between the Lower and Upper divisions of the New Red Sandstone should therefore be placed farther up the stream than it is placed on the One-inch Geological Map.[1] G.W.T.

Similar rocks are exposed in the Clauchan Glen, and also in a small burn which joins it from the south. On the eastern side they are bounded by the Upper Old Red Sandstone; on the west by the marls of the Triassic. The breadth of the strip is nearly 500 yards, and the dip is generally to W.S.W. at angles of 15° to 20°. On the west side is found a fine-grained, yellow, calcareous sandstone which

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[1] J. W. Gregory, 'The Permian and Triassic Rocks of Arran,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 181–182.

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weathers in a carious manner. Higher up there are flaggy yellow and whitish sandstones, and a little below the foot of the branch burn are some red or mottled marly bands, some of which appear in the branch stream where, in one place, alternations of red shaly bands and thin sandstones occur. Above the foot of the small burn the sandstone is fairly well bedded, pinkish or yellowish in colour, becoming harder and approaching to white, as the position of the bounding fault is neared. It cannot be said that the lowest of these beds differ materially from much of the older formation east of the fault, especially as between 100 and 150 yards above the little burn there occur three calcareous bands which are not unlike in character to the cornstones of the Old Red Sandstone. On the whole it appears more probable that the beds containing the calcareous bands are parts of the Trias, and belong to the higher part of the lower division, where calcareous concretions are known to occur in other places. W.G. (MS.)

The soft, thick, and rather false-bedded sandstones near the top of this division, which are carious (having many cavities in places), have been quarried west of Traighliath, where they form a narrow gorge in the Ballymichael Burn, and by the side of the Machrie Water about a mile from its mouth. At the latter locality the cavities are of various shapes and sizes, some of them very irregular, and one was observed more than a foot in length and upwards of an inch in breadth. The natives call these cavities *moss-holes.* These upper beds are finely exposed along the Tormore shore for about a mile south of Leacan Ruadh. The sandstone varies from a deep or almost brick-red colour to yellow or white, and the changes, sometimes rather abrupt, are not easily accounted for. At the north end of the section the beds dip to the north-east at 10°, and this direction continues for some distance, so that as we advance southward lower and lower beds successively rise from the shore and form the cliff. Then the beds for some distance remain horizontal, but before reaching An Cumhann the strata begin to dip gently to the south-east, and we observe the rocks a second time as we proceed southward. The carious and false-bedded sandstones enclose lenticular masses which seem slightly calcareous, and the weathering of some of the rock is very curious and irregular, sometimes not unlike bunches of grapes. Much of the sandstone is quartzose and rather coarse, but the bunches and lenticles are formed of a finer and harder rock, concretionary in structure. The massive red and yellow sandstones in which the large caves are formed are the highest part of this series, and a short distance to the southward we find these beds passing under the marls of the Trias. W.G.

In the Machrie Burn the typical, soft, thin-bedded, red sandstones of the Lamlash–Machrie group are well exposed in a gorge 300 yards north of Machrie Farm, and in a newly-opened quarry in the same locality. The dip is 27° to the south-south-west. Sun-cracked shales with sand 'dykes' occur in the stream bed near the farm. At the bridge adjacent to the farm, white, yellow, and pink massive sandstone dipping at 5° to the south-west no doubt represents the base of the Glen Dubh Sandstone horizon.

A similar section is seen in the Machrie Water five-eighths of a mile west of Derenenach. The sandstones here are soft, red, shaly, flaggy, and thin bedded, and have a dip to the south-south-west of 20°. At a little gorge below the boundary of Machrie Wood, coarse, thick-bedded, felspathic, pink to white sandstones, with the usual blocky outcrop on the adjacent moor, and smooth-weathering, but carious, surfaces, occur dipping south-west at 5°. Boulders of this rock may be traced across the moor for at least half a mile to the north-west. G.W.T.

LITHOLOGY OF THE BRECCIAS AND CONGLOMERATES OF THE LOWER NEW RED SANDSTONE

Mr. B. H. Barrett[1] has studied the lithology of the Brodick Breccias as developed along the Corrygills shore, in Glen Dubh, the Machrie Water near Derenenach, and at the Cock of Arran. At Corrygills it was found that fully 75 per cent. of the pebbles were vein-quartz, and a varying proportion of the remainder were quartzites. Schistose grits like those of the Highland border, quartz-biotite-schists like those of the north of Bute, slates, greywackes, a dolomite very similar to that occurring in the Highland Border Series at Aberfoyle, cherts, and white and red sandstones, were also found. This assemblage of pebbles seems to have been derived from regions to the north and north-west of the island. In the Machrie Water the pebbles were almost entirely schists and quartz, and the best example of a pebble of Ben Ledi Grit was found here. In Glen Dubh, jasper and felspar-porphyry were relatively common in addition to the ubiquitous schists and quartz. At the Cock of Arran, schists and quartz again constitute the prevailing pebbles with red and white sandstone, shales and limestones of Carboniferous types. This is the exposure whence Messrs. Wünsch and Thomson obtained the derived Carboniferous fossils (p. 84). Mr. Barrett's conclusions are that the Brodick Breccia is of local derivation, and was deposited by infrequent river floods, which came from the north (Cock of Arran ; Brodick ; Corrygills), from the north-east, bringing Bute material, and from the west (Machrie Water and Glen Dubh).

The horizon on the Corrygills shore which is taken as marking the base of the Lamlash Sandstone or the top of the Brodick Breccia, contains numerous agates, associated with granite pebbles of Old Red Sandstone types, and with felsite and mudstone, besides the usual schists, quartzites, and quartz. The pebbles in the band of conglomerate at Largybeg Point (p. 89) consist mostly of white and pink vein-quartz, with quartzites similarly coloured, and a few of red felspar-porphyry, flinty quartz-felsites, grey mudstone, red sandstone, and chert. The igneous and quartz pebbles range between 1 and 2 inches in diameter, and are mostly of a well-rounded shingle type. A few pebbles, however, show distinct facetting in three or four directions, with a flat base, and are unmistakably dreikanter. Nevertheless, the edges of these are frequently well rounded, and they have evidently suffered some water erosion in addition to their original wind-facetting. The igneous and quartzitic pebbles, whatever their present shape, are of distant origin. On the other hand, the sandstone and mudstone fragments, which are large and angular, are clearly of local derivation. The matrix is a coarse sandstone consisting mainly of rounded and polished grains of quartz and an occasional cleavage fragment of fresh felspar, embedded in a whitish, decomposed, felspathic base.

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[1] 'The Permian Breccia of Arran,' *Trans. Geol. Soc. Glasgow,* vol. xvii., part ii., 1925, pp. 264–270.

The whole aspect of the conglomerate suggests that it represents an accumulation of pebbles and sand brought together by the occasional rain-bursts which occur in a desert or sub-desert region. This would account for the mingling of rounded shingle pebbles and angular dreikanter in a matrix of desert sand.

Two specimens from the basaltic horizon in the Brodick Breccias of the Glen Dubh exposure were collected and sliced, one of the purplish-red type (24387), the other of the greenish-grey type (24388). The former is made up mainly of comparatively fresh basaltic fragments up to 1 cm. in diameter, many of which show traces of wind-rounding. The larger fragments, however, are generally angular. Mugearitic types constitute the majority of these fragments, but there are some typical red-speckled olivine-basalts like those of the Mauchline basin (Permian) on the mainland. Along with the basaltic fragments are a few angular chips of quartz-sericite-schist and quartzite, all embedded in an abundant carbonate matrix which appears to be dolomitic from its behaviour with acid.

The green rock (24388) differs from the above in its greater relative abundance of basaltic fragments, in their much more advanced decomposition (hence the green colour), and in the more calcareous nature of the cementing material. G.W.T.

CHAPTER IX

NEW RED SANDSTONE (*continued*)

UPPER DIVISION (TRIASSIC)

THE Upper Division of the New Red Sandstone is the sedimentary formation which builds the greater part of the southernmost quarter of Arran. Fine sections are exposed in the old sea-cliffs around the southern and south-western coasts, and in the lower courses of the streams debouching on these coasts. Up the western coastal region the Triassic marls and shales are found as far north as Ballymichael. A small detached area of Triassic rocks is preserved in an area possibly between two converging faults at the head of the Birch Burn (Lag a' Bheith) to the south of Brodick; and a few small masses of Triassic marls have been involved in the Central Ring Complex. The latter, however, are reserved for description in the succeeding chapter, in which all the Mesozoic fragments preserved in this way will be dealt with.

The rocks are chiefly variegated shales and marls of red, green, and grey tints, with some bands of sharp-grained and micaceous sandstones, calcareous sandstones, and impure nodular limestone. Thus the group is lithologically contrasted with the rocks of the Lower Division. They present the characters of aqueous deposits rather than those of deserts, and may be regarded as the varied accumulations of a river system. Some of the marls are crowded with minute calcite rhombs, and were probably laid down under lagoon conditions

The stratigraphical classification of these rocks is stated on p. 76. It differs from that proposed by Prof. J. W. Gregory[1] in the recognition of a lower series of marls and cornstones, typically exposed in the upper part of the Lag a' Bheith, which rests directly on the Glen Dubh Sandstones, and must therefore be on a lower horizon than the Levencorroch Marls and Cornstones. The order of description will be clock-wise around the coast, starting on the east side with the faulted outlier of the Lag a' Bheith. G.W.T.

In the Birch Burn (Lag a' Bheith) the rocks may be seen in both main headwaters of the burn, but the longer branch yields the better section. Overlying the red sandstones rather more than half a mile north of Cnoc Dubh, we find beds of red and mottled clays or argillaceous shales with occasional thin bands of nodular limestone. The dip is first to the south at a low angle, but higher up the stream the dip is eastward or undulating, and the strata are traversed by dykes or sills of felsite, pitchstone, and basalt. Traces of the mottled shales or marls, variegated red and green, are found occasionally up to near the head of the stream where it issues from a peat moss. The size of this patch of the upper beds appears to have been limited by faults on either side, which bring up the lower sandstones.

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[1] *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, p. 186.

In the region immediately west of Whiting Bay, the red and green marls and accompanying sandstones are well seen in the upper parts of practically all the small burns which drain into Glen Ashdale. They come on above the main Glen Ashdale dolerite sill (the one at the great waterfall); and to the north and west of Glen Ashdale they appear at the horizon of the widespreading felsite mass of Loch na Leirg.

The Allt Garbh, which flows by the west side of Borrach, on the north of Glen Ashdale, offers a typical section of these rocks, and shows the way in which they are involved with the Kainozoic igneous rocks. The gorge of Creag Bhan in this burn, immediately south of Borrach, exposes a rather complicated mass of igneous rocks, including spherulitic felsite, a 'felsite-basalt' composite sill, and several basalt dykes, with at least two demonstrable faults (Fig. 14). The true Triassic marls and shales, brick-red, tea-green, and ash-grey, are seen interbedded with soft marly sandstones and some thick posts of whitish and chocolate-coloured sandstone. Up to the igneous rocks of Creag Bhan the dip does not depart sensibly from the horizontal. The intrusions and the faulting, however, result in various inclinations, different on opposite sides of the gorge. There is nothing to indicate discordance between the marls and the underlying red sandstones.

One-eighth of a mile above Creag Bhan the spherulitic felsite of that locality passes under horizontal red sandstone and shale, and the sedimentary rock upstream of this point is a thin-bedded chocolate-coloured shale. Thence the stream passes into the extensive felsite mass of Loch na Leirg.

The Dippin section has already been described (p. 89).

G.W.T.

The Kildonan section eastward from Little Mill, is in soft marls with thin sandstones. The best sections are, however, inland, in the two burns of Allt na Ceardaich and Allt Mòr. The latter issues from Loch Garbad, and, where it passes through the wood above the road, runs in a deep gorge cut through the marls. This gorge is terminated by a waterfall forming the centre of a fine amphitheatre of rock, capped by a sill, which is divided into two parts by an intercalation of marls and sandstone. At the fall there are some small faults, and two thin dykes, each about 2 feet in width, running perpendicularly up the cliffs. The more easterly dyke appears to coincide with a fault, and apparently does not reach the sill, while the more westerly dyke seems to pierce it. The beds in both burns are nearly flat, but the general inclination seems to be towards the south-east. The Allt na Ceardaich, or the Smithy Burn, has a bed of sandstone above the wood, which is somewhat flaggy, red or white in colour, and in places has a carious weathering. Some of it is ripple-marked and alternates with shale, and the whole dips gently to S.S.W. Hard grey calcareous shale occurs higher up, which was carefully searched for organic remains, with a negative result.

W.G. (MS.)

Prof. J. W. Gregory[1] gives the following detailed section from a road cutting above the Kildonan shore, by the side of the Allt Mòr :—

	Ft.	In.
Red shale with green spots	6	—
Green shale	—	6
Light brown to buff soft sandstone..	1	2
Bar of hard buff sandstone	—	5
Green sandy shale	—	4
Buff to white soft sandstone, with layers of green shale ..	2	—
The green layers increase in proportion till they form a basal layer of green shale	1	—
Red nodular shale, ending below in a line of green patches	3	—
Red nodular shale	5	—
Green shale	—	8
Buff coarse sandstone	—	2
Buff sandstone decomposed to sand	—	3
Green shale	—	6
Red shale	—	6
Green shale	—	3
White to buff sand with brown spots ; in part false-bedded	1	3
Green shale	—	—
Bar of white to brown or buff sandstone	—	4
Red nodular shale	4	—
Total	27	4

The corresponding section in the Levencorroch Burn is also described by Prof. J. W. Gregory.[2] In the upper part of the stream the beds are almost horizontal. The sequence from the base of the Auchenhew dolerite sill at 620 feet is as follows :—Immediately below the sill are chocolate and reddish shales, followed by alternate layers of red shale and white sandstone. Some of the shales are green-spotted. Below the upper waterfall, at a level of 570 feet, are some light-blue calcareous sandstones rich in white mica. Some of this rock is well bedded and some is false-bedded. The rock weathers into cavities, and effervesces freely with acid. The surfaces of some of the sandstone layers are marked by a network of raised bands, due to the sands having been pressed into shrinkage cracks in the adjacent beds of clay. The red shales in this part of the section are accompanied by red marls, which have the typical irregular fracture of the English Keuper marl. At the level of 525 feet are two layers of calcareous nodules or potato stones, which are secondary calcareous segregations. At 495 feet is another waterfall due to a basic sill, and below it occur further red marls and green shales. At 450 feet is a lenticular bed of quartzite. Thirty feet below it, at the end of the main section, are thicker bands of bluish-white sandstone, with some of the markings usually described as fucoidal ; they are about a quarter of an inch wide and branch repeatedly. These sandstones have layers which owe their light colour to the abundance of white mica. Some of the bands are brecciated by settlement of the rocks during consolidation.

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[1] 'The Permian and Triassic Rocks of Arran,' *Trans. Geol. Soc. Glasgow,* vol. xv., part ii., 1915, p. 178.

[2] *Ibid.*, p. 177.

The dip at the lower end of the section is about 7° north. A grass-covered slope extends down to the road, broken by one exposure of red and green shales. South of the road a gully shows occasional exposures of red shales on the floor of the hanging valley above the waterfall at the mouth of the Levencorroch Burn. Beneath the fall are red and green shales, which have been cut through to the underlying white calcareous sandstones and chocolate-brown sandstones; and these are succeeded, at the lowest point exposed, by more red and green shales.

According to Gunn, a fault which has a westward hade of 45° is clearly visible at the Levencorroch waterfall. It runs down on the west side of the burn, and must have a downthrow to the west of 100 feet, and perhaps much more. The sandstone itself is cut off by the Levencorroch dolerite sill. This fault also affects the rocks which appear in the cliff east of the lower part of this burn. On the west of the fault there occur marls overlying a set of flagstones; while east of the fault the flagstones (or a lower set) are raised to the top of the cliff, and continue in this position, associated with marls, nearly to Little Mill. G.W.T.

The section from the mouth of the Sliddery Water eastward to Bennan Head is described by Mr. Gunn as follows:—East of Sliddery Water, on the shore, a great breadth of rock is exposed in places at low water. The dip is here usually to west of south at 5° to 10°, and the rocks consist of red marls and thin sandstones. On either side of Torrylin Waterfoot the foreshore is covered with sand and shingle, and not much rock appears. Up the stream, however, there are fine sections in the banks about Lagg, in the lower part of the Cloined Burn, and the small streams near Laigh Clauchog. The dip is generally to the south-west, and in the Cloined Burn amounts sometimes to 30° or 40°. This high dip, however, does not appear in the Kilmory Water near the church, where the rocks form a low, anticlinal arch. Probably a large fault ranging north-east intervenes between the two outcrops.

W.G. (MS.)

Prof. J. W. Gregory[1] has described sections in the Allt Mòr Cloined and its tributary from High Clauchog. At the confluence of the tributary and the main burn the following section occurs:—

Red and green shales, with four or more ribs of sandstone, from 2 to 6 in. thick.
Red shaly sandstone or mudstone breaking into small irregular fragments, 3 ft.
Sandstone rib, bordered above and below by green shales, 6 in.
Red shale, with green spots, and red or chocolate argillaceous massive sandstone, 8 to 10 ft.

The section in the tributary begins with red shales, which contain layers of red sandstone from 1 to 10 inches thick, and dip 15° to the south. The sandstones are sometimes white, with green spots and lines; and some of the red shales are much jointed with flat surfaces instead of the curved fractures of the typical red marls. The burn level rises more quickly than the beds, and younger members of the series are therefore exposed higher up. A cliff on the right bank consists of massive sandstone, which is buff-coloured, with green lines; and below this is a section as follows:—

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[1] 'The Permian and Triassic Rocks of Arran,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, p. 179.

	Ft.	In.
Red shale	5	—
Alternation of sandstones and red and green shales ..	6	—
Rib of earthy limestone	—	6
Red shale with some horizontal green streaks	—	8
Clayey limestone	—	1–4
Red shale	2	—
Potato stones	—	4
Red shale	2	6
Layer of larger potato stones	—	5
Red shale passing down into red sandstone	6	—

This part of the section may be correlated with the calcareous horizon of the upper part of the Levencorroch Burn. G.W.T.

Returning now to the shore-section, the old sea-cliffs along the Torrylin shore, north of Eilean Mairi, afford in one place a section of 60 or 70 feet of red marl with bands of nodular limestone, and one sandstone band a few feet in thickness. Above these, to the east, come alternations of marls and thin sandstones; and near the thick felsite dyke is the base of a thick mass of yellow sandstone which stretches a long way to the eastward. It may have been this mass which was encountered in a boring at Kilmory Manse, where, beneath 45 feet of till, and 33 feet of marls, etc., a thickness of 85 feet of sandstone was proved. In the cliffs the sandstone appears to dip gently to the east, and there are no high dips except close to the felsite dyke, which has much altered and disturbed the strata. Close to high-water mark the sandstone contains calcareous concretions. At Eilean Mairi the rock dips to the south, at a low angle. Between the cliff and the shore a fault passes with a southward downthrow. About 350 yards to the east of the large felsite dyke there may be seen near high-water mark a few feet of fine calcareous-looking yellow sandstone full of nodules like marbles. Above, and to the east of this, is a thick mass of coarse and pebbly, red, false-bedded sandstone. In one place the false-bedding may be observed to dip south at 20°, while the true dip is eastward at a low angle. The marls which overlie the sandstone are well exposed in the small stream west of Shannochie; and from the burn east of Torr nan Uain, for half a mile to the eastward, the cliffs, 200 feet in height, are composed mainly of red, with some grey, marls. There are several thin bands of yellow-white sandstone, and near the top of the cliff are several layers of nodular, light-coloured limestone. The highest beds that appear are of sandstone, close up to the Bennan Head quartz-porphyry. The rocks have a gentle easterly dip all the way. On the shore farther east, however, but still west of Bennan Head, the dip changes to the south-west. At the Head itself, igneous rock occupies the cliffs for some distance. The marls appear again at Port a' Ghille Ghlais with a south-westerly dip, and are visible also in the cliffs. Opposite Levencorroch an anticline occurs, and the beds dip easterly again for a long distance.

W.G. (MS.)

According to Prof. J. W. Gregory,[1] north of Bennan Head the Keuper beds include a layer of sandstone which is almost as compact as a quartzite. West of Bennan Head, on the cart road from the shore to the top of the cliff of Torr nan Uain, is an excellent exposure, which, in descending order, gives the following section :—

	In.
Nodular red marl, with curved irregular fractures	3
Red shale	10
Red nodular marl	3
Red shale	15
Potato stones	2
Red shale	14
Band with occasional large potato stones	2½
Red shale	3
Potato stones	2
Red shale	6

The lowest part of the section consists of red mudstones, shales, and marls, some of which have the aspect of typical Keuper marls.

G.W.T.

East and south-east of the great mass of quartz-porphyry at Brown Head, good sections of the marls are obtained in the Corriecravie Burn, and at Port na Feannaiche. Along the shore to the eastward rapid alternations of marls with thin sandstones, which dip south at 12° to 15°, are encountered. As the mouth of the Sliddery Water is approached, there is an occasional ripple-marked grey sandy bed ; and several small faults are visible crossing the outcrop on the foreshore. West of the Sliddery Water one of the sandstone bands may be traced for 500 yards at low water parallel to the shore.

Inland the best section occurs in the lower part of Allt na Pairce for about a mile above its junction with the Sliddery Water. The banks, more particularly that on the west side, reveal frequent alternations of thick beds of red marl with thin bands of soft yellowish sandstone. The dip is pretty regularly to S.S.W. at angles of from 12° to 15°. Sections in the Sliddery Water and the Allt Burican have already been noted (p. 91)

Among the complicated igneous masses of the southern interior of Arran the marls and sandstones crop out for short distances in various places, as, for example, in the upper part of the Allt Dhepin, the Allt nan Clach on the south-east of Tighvein, and in the neighbourhood of Smuraig. The Allt nan Clach section shows red marls with subordinate green and red sandstones. There is a good section in the Allt an t-Stuie (one of the headwaters of the Kilmory Burn, 1½ miles S.S.W. of Tighvein), where the general dip in the higher part is W.S.W., or in the same direction as the sandstones of the lower division of the New Red Sandstone, which are found on the high ground on the other side of the big intrusive masses. The position of the two subdivisions is here inexplicable unless the igneous rocks conceal a large fault with a downthrow to the south-west. A fault in a north-east direction is probable, as was suggested to explain the relations west of Kilmory Manse; and this, if prolonged through the ground now occupied by the igneous rocks, would account for the relations of the marls to the lower sandstones in this obscure and difficult ground.

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[1] 'The Permian and Triassic Rocks of Arran,' *Trans. Geol. Soc. Glasgow* vol. xv., part ii., 1915, p. 178.

Lower down Allt an t-Stuie, and about half a mile north of Auchareoch, are some red and green marls and mudstones with cubical shapes which are probably pseudomorphs after salt. Some disturbed thin grey beds north-west of Auchareoch, in the same burn, seemed likely to yield fossils, but none were obtained. The only locality where these rocks contained traces of organic remains is Allt na Pairce, to the west of the Sliddery valley. Here obscure traces of plants were obtained by Mr. Tait, as well as pseudomorphs after salt.

The western sections begin near the King's Cave, to the north of Blackwaterfoot, where the boundary between the upper marls and the lower sandstones is sharper than usual. The sandstones, massive red or yellow, are found at the caves. The colour is not of much importance. North of the caves carious yellow sandstone overlies red sandstone. Farther south, rock of the one colour passes laterally into the other, and south of the caves some 30 feet of red sandstone overlies yellow. The basalt dykes hereabouts have come up along lines of faulting, and the sandstone is bounded by the most northerly of these, which throws down the marls on to the foreshore, on the east side. The dip is here easterly at a low angle, and the shore is occupied by a strip of marls overlying another strip of sandstone on the west. The next dyke to the south throws down the marls a few feet in the same direction as before; but the third dyke, which throws in a contrary direction, shifts the boundary eastward. A short distance farther is a fault trending north-west on the shore, which cuts off the sandstones entirely; and beyond this, both on the shore and in the old sea-cliff, there are red marls, sometimes of a grey colour, with bands of thin sandstone, as far as the cliffs of Drumadoon. The dip is usually south-east at a low angle, generally not more than 4° or 5°. After passing the Drumadoon quartz-porphyry sill there occur various outcrops of sediments opposite the golf course on the shore. Yellow sandstone dipping south-east occurs near the point, but towards the east end of the links marls and sandstones occur dipping westward. Among these rocks appear several thin nodular calcareous bands accompanied by hard grey sandstone. Near the intrusive felsite mass of Blackwaterfoot the rocks dip at an angle of 45° to 60°. In the cliff north of this locality is a kind of cave above which appears a patch of purple shale alternating with bands of yellowish sandstone. These rocks, which are about 20 feet in thickness, dip gently to the west, and are bounded on either side by felsite. Another small area of sedimentary rock apparently surrounded by intrusive igneous masses occurs at a farmhouse in Torbeg, on the east side of the road, and 1100 yards north of Blackwaterfoot. It consists of a strip of red shaly sandstone some 40 yards in breadth, which dips north at 25°. On the foreshore near low-water mark, some 200 yards south of Blackwaterfoot, is another sedimentary mass caught up in a felsite intrusion. It is a band of yellow sandstone 25 feet broad, which has a dip to north-west of 40°.

Alternating red marls and sandstones may be observed in most of the small streams that enter Drumadoon Bay from the east. The beds usually dip to the north-east at 5° to 10°. Perhaps the best of the sections is afforded by the stream called Allt Cul na h'Eilde, to the south of Cnoc Ballygown. The highest beds seen are yellow and red sandstones, which overlie red sandy marls, and then sandstone well exposed lower down the burn. Beyond the bend where the burn turns westward is a wooded gorge in the red marls, which are separated by partings of yellowish-white, and grey, soft sandstones. A band of thick, white, quartzose sandstone has been quarried in places to the west of Cnoc Ballygown. It dips to the south-west.

There are some good sections of the rocks in the lower part of the Clauchan Glen, particularly on the south bank of the stream. The dip is here south, as it is in the lower part of Allt na Glaic, the branch stream that issues from Loch Cnoc an Loch. Higher up this burn the dip changes to north, near the fork, and the highest sediments in this section, which are thin-bedded red and white sandstones of considerable thickness, are nearly horizontal.

W.G.(MS.)

CHAPTER X

MESOZOIC FRAGMENTS IN THE CENTRAL RING COMPLEX

THE Rhætic, Jurassic, and Cretaceous formations are represented in Arran by fragmentary masses which have been involved in the Central Ring Complex. The Triassic marls are also found with the same mode of occurrence ; and it was the association of these marls with Rhætic beds which led to the definite ascertainment of the age of the New Red Sandstone beds in the southern part of the island. The igneous rocks, both massive and fragmental, with which these fragments are associated, are elsewhere described. As will appear from the detailed description of the fragments which contain fossils, they do not occur in close proximity, and sometimes as much as a mile intervenes between one fragment and another. In addition to the fossiliferous masses, there are others of limestone, of sandstone, and of shale, in which no organic remains have been found. It seems probable that these also are of Secondary or Mesozoic age, though it is not possible in each case to determine to which formation they belong.

In several instances the fragments have been much altered by intrusive igneous rock, and some of them have Kainozoic dykes or sills traversing them. Especially is this the case with the largest of the fragments, which contains not only beds of Rhætic age but grey marls of the upper part of the Trias and a portion of the red marls which lie below.

W.G.

TRIASSIC FRAGMENTS

At the west end of Muileann Gaoithe (Windmill Hill), on the north side of Glen Ormidale, and about 2 miles west-south-west of Brodick, there is a remarkable inclusion of Triassic marls, which is apparently caught between two masses of quartz-felsite, one of which forms Windmill Hill itself, and the other builds the smaller hill (1296 feet), to the west. The fragment is bright-red in colour, and forms a conspicuous feature in the almost vertical southern face of Muileann Gaoithe from any viewpoint in the Ormidale valley, or from the ridges to the south. The patch is wedge-shaped, both horizontally and vertically, and has a length of about 25 yards inward from the edge of the cliff, and extends perhaps 20 yards downward into the steep gully below. It consists of brick-red, tea-green, and ash-grey marls, with irregular curving fracture planes, vertical or dipping steeply to the north and north-north-west. It is bounded by a fault on the western side, and is traversed by several lines of fault, one of which is filled by a band of fault-breccia 12 inches wide. The faulting is displayed diagrammatically in great perfection on the bare horizontal floor. On the eastern side the felsite of Windmill Hill appears to have an intrusive contact with the sediments, as the former rock shows a beautiful flow structure, and other chilling effects, at the junction with the marls. The bounding fault-plane on the western side is occupied by a little dyke, 8 inches wide, of porphyritic basalt.

This patch may have been dropped down an explosion fissure in the older, western felsite mass, which appears to pass into a large granophyre mass farther west. The fissure may have been sealed up by the later felsite intrusion of Windmill Hill, which spread out from the same orifice.

Another smaller patch of red marl is to be found to the west of the main mass, a little way down a steep, grassy slope. Its relations cannot be determined, but felsite appears *in situ* between it and the larger mass.

These marl fragments are believed to be connected with a much more extensive area of presumably Mesozoic rocks, which run through the felsite masses of Windmill Hill in a north-east to south-west direction, from a point well down on the north side of Windmill Hill to the northern headwater of the Ormidale Burn. These rocks were formerly mapped as Carboniferous, and were described as such in the Memoir on Sheet 21.[1] They consist of chocolate-coloured, sandy, micaceous shales, and whitish sandstone, with a dip of 70° to the west in the peaty gully on the north side of Muileann Gaoithe. In the northern headwater of the Ormidale Water, masses of hard quartzitic sandstone are found involved with felsite in a very complicated manner. A crag to the north of the burn consists of coarse, white, gritty sandstone dipping north-west at 20° to 30°. Traced to the east this sandstone appears to become baked, and is intersected by thin tongues of felsite. On the same line of strike other sandstone patches are found; and Mr. E. B. Bailey, when traversing these exposures with the writer in September 1925, found a patch of grey-blue sandy shale, only a few feet wide, which yielded indeterminable ammonites. Dr. G. W. Lee suggests that these fossils belong to the *Planorbis* Zone of the Lias. This patch can be easily found; it occurs on the west side of the gully which lies to the west of the Triassic patch on Windmill Hill, about 120 yards south-south-west of the summit of that patch. G.W.T.

RHÆTIC ROCKS

A short distance north of the farmhouse of Derenenach, two small streams which have cut gorges in the low-lying mass of granophyre cross the road. The longer and more northerly of these two burns is called Allt nan Dris, and is the only one of the two which is marked on the One-inch Map. In the middle part of its course this stream traverses the largest of the identifiable fragments in the volcanic vent, which is of an irregular shape and extends over several acres. It is probably quite a quarter of a mile in length from north to south, and its width is at greatest about 150 yards. This patch contains the black shales and thin limestones of Rhætic age, which are exposed for a length of nearly 90 yards in Allt nan Dris about a quarter of a mile north-east of Derenenach. The greater portion of this fragment, however, consists of grey and red Triassic marls, the red marls forming the bulk of it. One cannot be quite certain about the actual order of succession in this mass, as the rocks are broken, or faulted and disturbed, and we do not see the different subdivisions actually in contact, but the following is the probable arrangement in descending order :—

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[1] 'Geology of North Arran, etc.', *Mem. Geol. Surv.*, 1903, p. 43.

Black shales and thin grey limestones of Rhætic age.
Greenish-grey or pale-coloured compact marls—Upper Keuper.
Red Marls—Keuper.

These beds are bounded on the west by the Derenenach granophyre, which occupies a strip of ground nearly a quarter of a mile in width between them and the road. They are best reached by following the burn upwards. On coming to the old sheepfold some of the red marls or mudstones may be noticed in the slope opposite with a high dip to the west, and they are also exposed in a small branch stream which we pass on the left. Soon the stream inclines more to the eastward, and we find in it a considerable section in the red marls, which appear to be nearly flat or have a gentle inclination eastward. The section is somewhat obscured, however, by several sills and dykes of felsite. Above this steep part the stream takes a sharp turn to the left and we lose sight of the rocks. A little higher up on the south side we observe the grey marls in the bank, lying nearly horizontal or with a gentle dip to the south-west, and a few yards farther we come upon the Rhætic black shales on the same side. They do not occur here, however, on the north-east side, but are opposed to the grey marls which on the north-east side are at a higher level than the Rhætic shales of the south-west side, so that there is manifestly a fault or break of some kind along the burn. Nearer to the sharp bend there occurs in one place a mass of the Rhætic shale containing thin limestone bands on the north-east side, and it was from this locality that all the best specimens were obtained. We do not, however, see the relation of this mass to the grey marls, and the junction is probably not natural.

The black shales on the south-west side of the stream here have yielded organic remains, but they are in a crushed and fragmentary condition. Altogether these Rhætic shales seem to be more disturbed than either the red or grey marls, and it is impossible to make out any order of succession in them. Often they appear to be nearly vertical, as in the fragment from which the fossils were obtained. The whole length of the exposure is in a small rocky gorge, and about 40 yards of it is below the sharp bend where the stream turns from a south-east to a due east direction. Above this bend the black shales may be traced for about 50 yards on the south side of the burn, but they do not extend so far on the north side. It seems probable, however, that they may occupy a considerable area to the south-west of the bend in the stream, where there is a smooth grassy slope, and excavations here might reveal other fossiliferous bands. The exposures above the bend in the stream have yielded no fossils.

The grey marls, as we have stated, appear on both sides of the stream, but the outcrops are not exactly opposite, as they are higher up on the north side, and opposed to the Rhætic beds on the south side.

These rocks were surveyed in the year 1899, and their peculiar characters, as being unlike anything occurring elsewhere in Arran, were remarked on. Specimens of the dark ferruginous shales were obtained, and were supposed to resemble certain rocks occurring in the Old Red Sandstone near Strathpeffer and elsewhere in the north of Scotland. In May 1900, however, A. Macconochie, the fossil-collector of the Survey, was successful in obtaining undoubted organic remains from the beds, and the collections made by him on being examined by E. T. Newton were referred to the Rhætic beds.

The following is Newton's determination of the specimens :—

FOSSILS FROM THE RHÆTICS OF SHISKINE, ARRAN

Pteria contorta (*Portl.*)
Pecten valoniensis *Defr.*
Schizodus [Axinus] cloacinus *Quenst.*
Protocardium philipianum ? *Dunk.*
(=C. rhæticum *Merian.*)
Modiola minima ? *J. Sow.*
Estheria minuta ? *Goldf.*
Gyrolepis alberti ? *Ag.*

Nearly three-quarters of a mile distant from the Rhætic beds in Allt nan Dris in a north-east direction, and about the same distance south of Glenloig, is a mass of unfossilferous shale which may belong to this formation. It is about 35 yards in length from N.N.E. to S.S.W., and is nearly vertical or dipping steeply to E.S.E. The rock, much altered and hardened to a kind of blue porcellanite, is bounded on the east by volcanic agglomerate and on the west by an intrusive mass of quartz-felsite. The volcanic agglomerate has undergone much alteration as well as the shale, and there is not much hope of obtaining fossils from this locality.

LIAS

The locality in which the Lias fossils are found is about 1 mile south-east from that of the Rhætic patch in Allt nan Dris, and nearly half-a-mile due south from the top of Ard Bheinn. It is 300 yards north of a fork in the Ballymichael Burn, and near the head of the glen in a dry gully on the north-west side of the stream. The patch consists of brownish, crumbling, calcareous shale and impure decomposed limestone, in some parts of which fossils are abundant, but mostly in the form of casts. The exact area occupied by this shale cannot be ascertained, but it is probably 100 yards in length and nearly 50 yards in breadth. Between it and the stream is found a yellowish granophyre, and on the north-east side occurs a fine, dark, basic rock. On the south-west side of the shale occurs the volcanic agglomerate with an apparently vertical boundary, and in one place the two rocks seem somewhat mixed.

The late Dr. B. N. Peach, to whom this singular fragment of a formation was shown, was the first to obtain fossils from it and to recognize their Liassic facies; and the collection then made (June, 1900) was despatched to E. T. Newton, who fully confirmed Peach's observations. In October of the same year a further search at this locality was made by Macconochie, which resulted in considerable additions to the original list. The fossils all belong to the Lower Lias (Angulatus Zone), and no traces of any beds that will fill up the gap between these rocks and the Cretaceous formation have been found, so that it is very probable they were related to one another in Arran as they are in Ireland, where the Cretaceous rocks repose unconformably on those of the Lower Lias. Newton examined the whole set of fossils from this locality, and furnished the following list of them :—

FOSSILS FROM THE LOWER LIAS (ANGULATUS BEDS), ARRAN

Cf. Schlotheimia angulata (*Schloth.*)
Amberleya acuminata *Chap. and Dew.*
Cerithium semele ? *Martin*
,, sp. (*cf.* falsani *Dumortier.*)
Pleurotomaria tectaria *Tate*
Arca ?
Astarte sp.
Pteria lanceolata *Sow.*
Cardinia listeri *J. Sow.*
Cardita heberti *Terq.*
Goniomya sp. (*cf.* rhombifera *Goldf.*; and sinemuriensis *Oppel*)
Gryphæa arcuata *Lamarck*
Inoceramus [Crenatula]
Lima pectinoides ? *J. Sowerby*
Lima succincta *Schloth.*
Modiola sp.
Myoconcha psilonoti ? *Quenst.*
Nucula sp. (2 forms.)
Nuculana [Leda] tatei *Newton* (=L. renevieri *Tate*)
Nuculana sp. (*cf.* quenstedti *Tate*)
Ostrea irregularis ? *Quenst.*
Pecten subulatus ? *Goldf.*
Pholadomya ?
Protocardium truncatum ? *J. de C. Sow.*
Tancredia ? peachi *E. T. Newton*
Unicardium cardioides *Phillips*
Ditrupa globiceps *Quenst.*
,, sp.
Serpula sp.
Pentacrinus basaltiformis *Miller*
Wood.

CRETACEOUS

Rather more than a mile to the east of the road Ballymichael Glen branches into two. A small stream comes in from the east, but the main valley continues in a north-east direction. A few yards above this fork there are lying at intervals in the bed of the main stream some blocks of a light-coloured limestone containing irregular lumps of chert or flint. They are not numerous, and have been apparently derived from the coarse volcanic agglomerate which forms here the western bank of the stream; for about 60 yards from the branch stream a small trail of these limestone blocks was observed on the slope. There is, however, no mass of the rock anywhere, and no fragment large enough to be indicated on a map of any scale. The limestone of these blocks is in character remarkably like that of the chalk of Ireland, which is not a soft friable rock like that of England, but a hard and compact limestone, especially where it has come in contact with igneous rock. The siliceous concretions in the limestone are irregular in shape, and occur just like flints in chalk or like chert in cherty limestone. They are almost pure white, certainly lighter in colour than the limestone itself, and they project on a weathered surface. The limestone itself is compact, fine grained, and of a grey colour.

This locality is only about 200 yards south of the patch or fragment of Lias already described, and the volcanic agglomerate occupies the intervening ground.

These blocks were noticed by [Dr.] B. N. Peach in June, 1900, who remarked at the time on their resemblance in character to the Antrim chalk. They were afterwards, in October of the same year, searched by A. Macconochie, and the organic remains were examined by E. T. Newton, who furnished the following list :—

FOSSILS FROM THE LIMESTONE AND CHERT OF BALLYMICHAEL GLEN, SHISKINE, ARRAN

Inoceramus (piece of shell showing prisms)
Polyzoa (Entalophora ? and Escharina ?)
Echinoderm fragments
Porosphæra globularis *d'Orb.*
Hexatinellid sponge fragment (Plocoscyphia ?)
Tetractinellid and other spicules
Globigerina cretacea *d'Orb.* (and other species)
Textularia, etc., etc.

Rather more than a mile N.N.W. of this locality, and 1100 yards north-east from Derenenach, a mass of cherty limestone of the same character occurs in a cave on Ard Bheinn, and some specimens of the limestone taken from this cave contain Cretaceous foraminifera. This 'Pigeon Cave,' as it has been called, can be traversed for many yards sloping downward in a west-south-west direction. The arched roof of the cave, which slopes downward like the floor, appears to be composed entirely of basic igneous rock—one of the numerous intrusive masses of the vent. On the north side, near the entrance, occurs 2 to 3 feet of dark-coloured hardened shale, which dips westward at 20° to 25°. Below this the section is somewhat obscure, but appears to be first basic igneous rock, then a light-coloured crystalline limestone—the Cretaceous rock—and afterwards a white baked sandstone or quartzite. These rocks on the north side are cut out on the south side by the arching over of the trap roof. Some of the limestone of this locality is converted to crystalline marble by igneous action, and all traces of organic remains have been destroyed.

Probably other patches of the limestone occur in the agglomerate of this neighbourhood, as there is a line of swallow-holes about 200 yards south-west of the cave, and there is one about the same distance due south from the cave.

Three-quarters of a mile north-east from the 'Pigeon Cave' of Derenenach is another cave in which limestone occurs, about 500 yards south of Glenloig. The locality where this occurs is called Creag an Fheidh, and there is a steeply-sloping hollow about 20 yards wide running in a north-north-east direction and bounded by crags on either side. On the western side of the hollow, and running in the same direction as it, occurs a basalt dyke 4 feet in width, and there appears to be on the east side another dyke the width of which is not clear. The cave is on the western side of the hollow, and has a slanting opening some 12 to 15 feet high. It runs back at right angles to the hollow about 15 yards at the north end. It is at this part of the cave that the limestone is visible, but it is very irregular in thickness, and only some 2 to 3 feet at the most, though, as the rock was once quarried, it may have been much thicker. It occurs in association with sandstone and some shale, and dips to the N.N.W. apparently from 30° to 40°. A patch of limestone may also be seen at the foot of the crag on the eastern side of the hollow. The limestone at this locality is much altered by contact with intrusive igneous rock which overlies it, and which has converted it into crystalline marble. There is no trace of chert in it and no organic remains, so that it is doubtful to what geological period it belongs. The cave has no doubt been enlarged by artificial means, but it is certainly to a great extent natural, and water sinks at the western end at a place now covered by loose stones. Probably this was at one time open. An old road leads up to the cave.

Headrick [1] noticed the occurrence of limestone at this place, but was mistaken as to its mode of occurrence, and in another part of his work he gives the following analysis of the limestone (p. 345) :—

GLENLOIG CHALKY LIMESTONE

Carbonate of lime	98
Clay	2
	100

OTHER MASSES

In addition to the above, there occur in the volcanic vent several large masses of a whitish, fine-grained sandstone, which probably are fragments of some Secondary formation. The largest of these is found in a line between the top of Ard Bheinn and the summit of Beinn Bhreac, and about 700 yards distant from the latter. It is some 250 yards in length and 15 to 20 yards in breadth, and forms a rather marked feature running in an east-north-east direction. It is bounded on one side by agglomerate and on the other by granite, and it appears to dip nearly south-east at an angle of 50°.

The next largest mass of the same kind is found about 200 yards south of the 'pigeon cave' and is oval in form, and apparently about 70 yards in length. Smaller patches of the same kind may be seen about 100 yards south-west of the same cave.

Other masses of sandstone occur about 150 yards north-east of the Rhætic patch in Allt nan Dris, and 200 yards north of the old sheepfold on the same stream. W.G.

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[1] Headrick, J., 'View of the Mineralogy, etc., of the Island of Arran,' 1807.

CHAPTER XI

THE KAINOZOIC IGNEOUS ROCKS

Introduction and General Summary

A rough measurement on the One-inch Geological Map of Arran shows that approximately 70 square miles, or a little less than half the area of the island, are occupied by igneous rocks of Kainozoic age. These rocks form a connected suite, the petrographical characters of which are similar to those of the Kainozoic suites of Skye, Mull, and Ardnamurchan. The age of the Arran rocks cannot be so definitely determined as in the latter cases, as there are no contemporary lava flows, and no Kainozoic sediments, in the island. The great majority of the igneous masses are of intrusive habit, and cut formations ranging from the Dalradian to the Triassic. The remainder are pyroclastic; and it is from the occurrence of Mesozoic fragments in the pyroclastic rocks of the Central Ring Complex that it becomes possible to fix the age of the Arran suite more definitely as post-Cretaceous (Chapter X). On the other hand, the excavation of the present valleys, probably in Pliocene times, cutting across dyke-filled fissures which would inevitably have flooded the valleys with lava had they been in existence at the time, imposes an upper limit of age for the igneous activity.[1] When the time needed to strip off the great dome of metamorphic and sedimentary rocks which must have covered the northern granite boss, and to carve a plane of erosion which was subsequently uplifted in the Pliocene, is added, it becomes necessary to shift the date of the igneous episode back to at least the early middle part of the Kainozoic.

Owing to the intrusive habit of the rocks, and the lack of any contemporaneous stratigraphical datum planes, it is more difficult even than it has been found in Skye and Mull to establish the age-succession of the various igneous groups. But what evidence is available supports a succession which is broadly comparable to those established in the above-mentioned regions. During the short survey of the Kainozoic igneous rocks which was made in preparation for the present Memoir, it was not found possible to deal with them in the detailed manner necessary for the establishment of a complete succession. The succession given below is therefore simpler and more general than it can be in actual fact, and many questions as to the age-relations of certain rock groups have been left over pending more detailed work.

In Mull the Kainozoic succession opens with a regional outpouring of undersaturated ‘plateau-basalts,’ which was followed by the more localized eruption of oversaturated ‘central-basalts’ from dome or shield volcanoes of Hawaiian and Icelandic type. The main igneous activity subsequent to these volcanic episodes was concerned with the intrusion of great basic plutonic masses, followed by more acid types, accompanied by associated minor intrusions. This succession is also well seen in Skye, but is complicated in Mull by the irregular superposition of two cycles of magmatic change and renewal.

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[1] *See* J. W. Gregory, ‘The Pre-Glacial Valleys of Arran and Snowdon,’ *Geol. Mag.*, vol. lvii., 1920, pp. 148 *et seq.*

In Arran there are no traces of plateau-basalts, or of central-basalt eruptions, unless certain large basalt, and basalt-tuff, masses, involved in the Central Ring Complex, represent lavas of these phases, which may have existed but have been totally destroyed by erosion, as the Rhætic, Jurassic, and Cretaceous formations undoubtedly were. But there are numerous large sills of analcite-olivine-dolerite, or crinanite, especially in the south-eastern quadrant, which almost certainly are the earliest Kainozoic igneous rocks of the island, and may possibly represent the underground manifestation of a plateau-basalt episode, the products of which have been removed by erosion, or have been faulted beneath the waters of the Firth of Clyde.

This phase of intrusion of undersaturated magma was followed by a great development of oversaturated magma, manifesting itself by the intrusion of plutonic masses in the central and northern parts of the island, and by the intrusion of numerous sills and dykes in the south. The magmatic succession in this phase was, as in all the other centres of Kainozoic igneous activity in the West of Scotland, from basic to acid. Gabbros and quartz-gabbros were injected into the central area, and quartz-dolerite sills of this episode make up many of the extremely numerous tabular igneous masses of the Glen Ashdale region. The development of the acid magma introduced an explosive phase, as in Mull and elsewhere, producing great masses of ‘ agglomerate ’ in the Central Ring Complex, and the varied phenomena of composite sills and hybrid mixtures which are so marked a feature of the southern half of Arran.

The third and final phase of igneous activity in Arran was the intrusion of numerous small acid dykes and sills, including the famous pitchstones, and the injection of a great congeries of basaltic dykes—the Arran Swarm—the main direction of which is N.N.W. to S.S.E. Dykes were no doubt intruded in connection with each of the main igneous episodes : some of them may even represent the vanished lavas of the Arran focus ; but the evidence is conclusive that the majority of the Arran dykes were injected at a late stage in the igneous history of the island, and indeed appear to have been its final manifestation.

The Crinanite Sills

Under this heading will be described the four large sill-like intrusions, and their offshoots, of the Clauchland Hills, Monamore Glen, Kingscross, and Dippin, which occur in the south-eastern quadrant of Arran. No large crinanite intrusions occur in the central or northern parts of the island ; nor do they appear in connection with the Central Ring Complex or the northern granite boss. The four above-mentioned masses apparently thin out in a westerly direction, and it is inferred that the focus or foci from which they were derived, must lie to the east under the waters of the Firth of Clyde. These rocks are entirely free from any connection with acid magma, and show none of the composite-sill or hybridism phenomena which characterize many of the presumably later basic intrusions.[1] Furthermore they are freely cut by many of the other igneous rock types of Arran. Their petrographical characters are fully consonant with those of the early plateau-basalt lavas of other parts of the Western Isles. For these reasons it is thought that the crinanite sills represent the earliest set of the Kainozoic igneous rocks of Arran. It is possible that some of the larger crinanite dykes, as, for example, the 70-foot north-west dyke near the Free Church Manse at Kildonan, represent the feeders of the sills.

A. FIELD RELATIONS

1. *The Clauchland Sill.*—This mass extends from the fourth milestone on the Brodick–Lamlash road westward to Dun Fionn and Clauchlands Point, a distance of 2½ miles. Its direction of extension is west to east as far as Dun Fionn, but at this point the outcrop makes a sharp turn to the south-east, and reaches the sea at Clauchlands Point. It is last seen in the Hamilton Rock just off Clauchlands Point. The average width of the outcrop is three-eighths of a mile, and its area is about one square mile. This igneous mass has the general form of a thick sill dipping at gentle angles to the S.S.E. or S.E. It has the peculiarity that, while its lower contact is mainly conformable to the New Red Sandstone strata into which the sill is intruded, its upper contact seems everywhere to be transgressive. The escarpment of the sill forms the steep northern face of the Clauchland Hills. Along this escarpment the sill rests quite conformably upon the New Red Sandstones, and only shows irregularities where it enters the sea. Here there is a steep contact with sediments which dip to the S.S.W. at angles of from 30° to 50°.

In places the lower contact is vertical or even overhangs, and the junction here is probably faulted. The shore-section near Clauchlands Point exhibits the entire thickness of the sill. For about a foot from the base it shows irregular banding of rocks of differing colours and textures, mostly fine grained or even basaltic, along with some coarser whitish veins. Above this the rock rapidly assumes a coarser texture ; at 20 feet above the base it is already decidedly coarse ; and towards the interior of the sill the rock occasionally becomes very coarse grained. Here also it carries pockets of pegmatite in which the lustrous black prisms of titanaugite may reach a length of 3 inches. Associated with these are thin veins and streaks of a whitish aplitic type very rich in zeolites (natrolite and analcite mainly), in which the felspars are highly zeolitized. The best place to see these phenomena is on the shore about 80 yards south of the wire fence at the lower contact. The upper edge of the sill passes under sediments which dip at 45° to the S.S.W., and the contact is complicated by the intrusion of a basalt dyke.

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[1] The statement made by the writer in ‘The Classification and Age of the Analcite-bearing Igneous Rocks of Scotland’ (*Geol. Mag.*, vol. lx., 1923, p. 257) to the effect that ‘they [the crinanite sills] constitute, in various modifications, the basic members of the composite sills and hybrid rocks, the mélanges of basalt and felsite, dolerite and granophyre, gabbro and granite, which occur so abundantly in the south of Arran’ is now known to be incorrect.

At its western end the Clauchland sill frays out into at least two separate intrusions consisting of fine-grained basaltic rocks, which are to be seen in and about the eastern headwater of the Lag a' Bheith (Birch Burn) on the west side of the Brodick–Lamlash road. Similar fine-grained dolerite is seen a few yards south of the fourth milestone, and in an old quarry a little south of the Standing Stones on the eastern side of the road.

From this point the southern boundary may be traced rather uncertainly eastward across the headwaters of the Blairmore Burn. In the eastern headwater of this burn a smooth slicken-sided scarp of fine-grained dolerite dipping 40° to the south, appears to plunge beneath the adjacent sandstones, and may here form a faulted junction. East of this burn there is a curious projection of sandstone into the heart of the igneous mass. The sandstone occurs in three or four well-marked scarps running approximately W.N.W. to E.S.E., and dipping about 5° to the S.S.W. These scarps are abruptly truncated by dolerite on both the eastern and western sides of the area. On the eastern side a good section is exposed in the burn running by Dunan Mòr and Dunan Beag. This section, and adjacent scarps, show plunging contacts of the sill against the sandstones, and a small subsidiary sill is injected into the sandstones under Dunan Mòr.

In the next gully to the east, one-third of a mile north-west of Lochan Ime, there is exposed very coarse pegmatitic rock, and adjacent to it there is fine-grained dolerite with coarse white acid veins. These alternations of coarse-grained and fine-grained rocks are fairly numerous, and are interpreted as *interior contacts*; *i.e.* the sill is believed to be multiple, and to have been emplaced by a series of intrusive pulses in rapid succession.

In the stream which descends the dip slope west of Clauchlands Farm, a plunging contact between the sill and sandstone is fairly well exposed. From this point to the Dun Fionn path, and thence to the coast, the boundary is uncertain, and can only be approximately fixed.

Along the northern front of the sill the boundary is well marked by a regular escarpment which runs eastward from Dun Fionn for about a mile, but which is lost under peat near the Brodick–Lamlash road.

2. *Monamore Glen.*—On the One-inch Geological Map of Arran (1910) this mass is represented as extending from Sguiler (1332 feet O.D.) in the south, across Monamore Glen, to Cnoc Dubh, and as occupying the whole of The Ross (989 feet O.D.) on the north side of Monamore Glen. From here the outcrop passes north over the

Benlister Burn, and extends up to Cnoc Dubh (1003 feet O.D.). It is thus represented as having a north to south extension of 2 miles, and an average width of half a mile. But the upper part of Sguiler consists of quartz-dolerite, and Cnoc Dubh consists of a porphyritic dolerite related to the quartz-dolerite group; the nature of the rock constituting The Ross is doubtful. True crinanite is found only in the Monamore Burn, in one of its southern tributaries, and in the Benlister Burn. Although the area has not been worked over in detail, it appears probable that there are two or three separate masses of igneous rock included under the same colour on the map.

The best section is exposed in the bed of the Monamore Burn west of the Mill Dam, half a mile W.S.W. of Monamore Bridge. The crinanite is here a coarse massive rock with few and irregular divisional planes. Occasionally it shows an extremely coarse pegmatitic facies, and also a fine-grained facies. These occur in irregular patches and streaks which fade gradually into the normal coarse-grained rock. The lower contact is seen a quarter of a mile west of the Mill Dam, and shows the crinanite resting on a felsite-granophyre sill. In the tributary which enters the Monamore Water a little to the west of this point the felsite sill is separated from the crinanite by a few feet of sandstone.

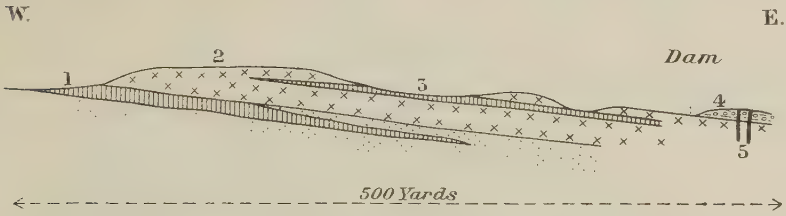

FIG. 8.—*Section along the Monamore Burn, west of Mill Dam.*

1. *Granophyre-felsite sill*; 2. *Monamore crinanite sill*; 3. *Felsite sill*; 4. *New Red Sandstone conglomerate*; 5. *Basaltic dykes.*

The upper contact is not well seen. The crinanite is last exposed in the Monamore Burn adjacent to the Mill Dam; and downstream of it, after a blank in the section, come hard-baked conglomerate and quartzite intersected by two basaltic dykes.

Two puzzling felsite exposures occur within the crinanite outcrop: a small one at the footbridge near the Mill Dam, and a larger one 80 yards to the west. This felsite appears to pass nearly horizontally beneath the crinanite, and may therefore be an inlier of the above-mentioned felsite sill at the lower contact. It may possibly be, however, a sill-like sheet injected at a higher horizon within the crinanite. The latter interpretation is favoured, as the crinanite mass appears to be too thick to have been cut through to its base (Fig 8).

The crinanite may also be seen in the tributary which enters the Monamore Burn from the south a little west of the Mill Dam. One-sixth of a mile from the confluence of the two streams the crinanite passes, with a sharp contact, under a sill of fine-grained xenolithic quartz-dolerite.

The crinanite is again exposed in the Benlister Burn, where it shows the same characteristics as in the Monamore section. At this place, however, it cuts transgressively across the edges of the sandstone strata, which dip mainly to the south-west.

As a whole the Monamore crinanite appears to form a sill dipping, as estimated from adjacent exposures of sandstone, about 20° to the south-east.

3. *Kingscross.*—The Kingscross crinanite sill occupies the peninsula of Kingscross between Lamlash and Whiting Bay, and enters the sea at Kingscross Point. It continues into the southern part of Holy Island. From Kingscross Point it extends westward for a distance of one and three-quarter miles, and then frays out into two or more thin intrusions. It is well exposed on the southern shore of Holy Island, and at Kingscross Point. There is a roadside exposure near Kingscross Bridge on the main road between Lamlash and Whiting Bay, and there are several rocky scarps near Auchencairn to the west of the road. The average width of the intrusion is a quarter of a mile, and its area must be about half a square mile.

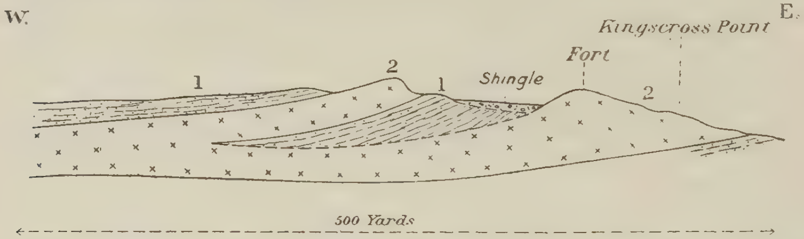

FIG. 9.—*Section across Kingscross Point, showing intercalation of sandstone* (1) *within the Kingscross crinanite sill* (2).

The lower contact of the Kingscross sill is well seen on the shore, a little south of the Stone Fort at Kingscross Point. The base is fine grained, but within 12 or 18 inches it passes up into a coarse-grained rock threaded with numerous acid veins up to 1½ inches thick. The reddish felspars in these veins have grown from the margins of fissures, and a median line of drusy cavities is often to be seen. The main body of the sill shows considerable variation in texture. In places pegmatitic phases appear in broad stratiform bands and also in irregular veins.

Around Kingscross Point and north of the Stone Fort, the sill plunges down, with a smooth glaciated upper surface dipping at 30° to the west, below sand and shingle. On the far (western) side of the little bay at this point, sandstone appears dipping west and underlying an outcrop of rock identical with that of Kingscross Point. Hence the sill appears to split into two branches, enclosing a sandstone intercalation (Fig. 9).

On the shore a quarter of a mile south of the Stone Fort the sandstones beneath the Kingscross sill are intersected by one or two small irregular basaltic sills, which include numerous interleavings of sandstone. One of these sills carries little groups of porphyritic felspars, and occurs only a few feet below the base of the crinanite. At Kingscross Point the crinanite shows a most striking penetration and veining by a dense black basalt with small white porphyritic felspars, which appears to be the same rock, but of somewhat denser texture, as that of the small sill beneath. The black veins penetrate the whitish-weathering crinanite in more or less regularly parallel bands which range from the merest threads to layers over a foot in thickness. In places there are numerous anastomosing strings of basalt joining up the bands and forming an intricate network (Fig. 10). The thicker bands and veins show distinct chilling against the crinanite. The vein-rock and the underlying thin sills are found, on petrographical examination, to belong to the quartz-dolerite–

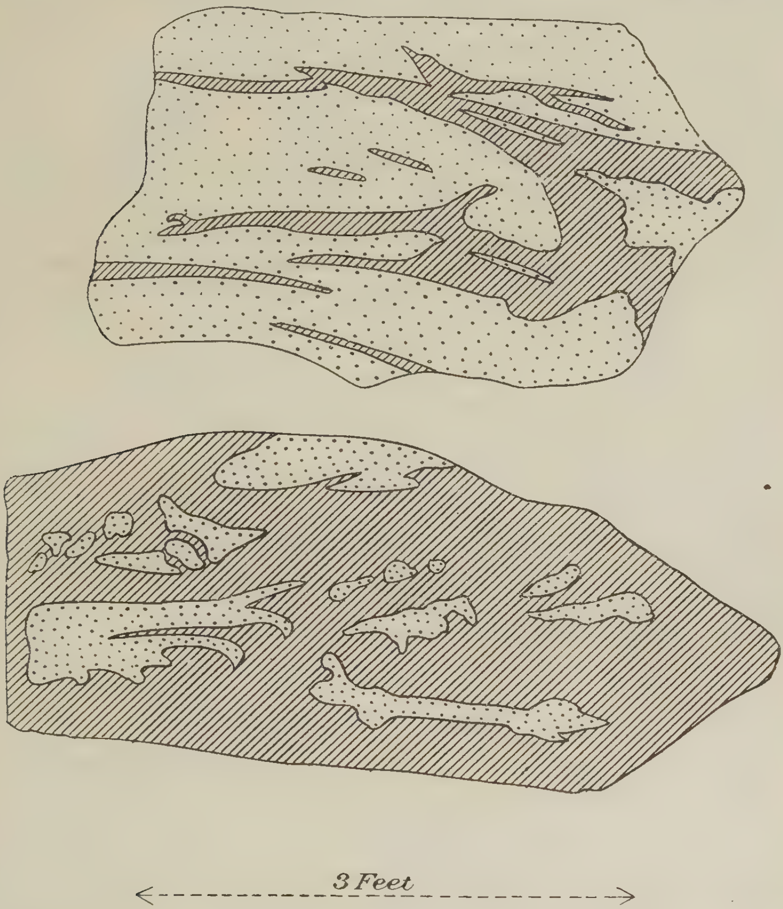

FIG. 10.—*Wave-washed surfaces of the Kingscross crinanite (dotted), showing its interpenetration by tachylytic basalt (line-shaded).*

craignurite group ; and this occurrence therefore serves to demonstrate the age priority of the crinanite sills.

The section through the crinanite afforded by the Kingscross Burn is poor, and is much confused by basaltic dykes. The attitude of the sill to the strata is difficult to make out. The southern edge of the outcrop is certainly the lower contact, and the northern edge the upper contact ; and this seems to indicate that the sill is dipping gently in a general northerly direction, opposed to the general dip of the New Red Sandstone strata, which is, however, very small. The sill consequently seems to be slightly transgressive.

4. *Dippin.*—The widest spread of the Dippin sill is between the clachan of Dippin and Dippin Head, where the intrusion reaches sea-level. Here the width of the outcrop is about half a mile. From Dippin Head the rise due to the general south-south-east inclination of the mass, causes a narrow outcrop, less than one-eighth of a mile wide, to appear extending in a north-west direction on the east side of Cnoc na Comhairle, reaching a height of 800 feet, and then bending round into Glen Ashdale, where it comes to an abrupt end against the scarp of the Garbad quartz-dolerite. A rapidly-thinning tongue also extends south-west from Dippin Head, and disappears near Kildonan. The total length of the intrusion is therefore about 4 miles, and its outcrop covers about three-quarters of a square mile.

The most complete section occurs on the shore at Dippin Head. A fine range of cliffs runs down by Largybeg, reaching the shore about one-third of a mile north of Dippin Head, where the cliff is about 200 feet in height. The lower contact is exposed at this point. The sill rests on baked purplish shales which dip N.E. at 15°. Several north-west–south-east dykes cut the sill at this place. At the lower contact the sill consists of a fine-grained basaltic rock with sparse microphenocrysts of felspar and olivine. It passes rapidly up into the normal coarse-grained type, with the usual pegmatitic streaks and aplitic veins. As seen in the cliffs the sill has a rude columnar structure, and is divided by massive, widely-spaced, vertical joints. Its upper contact is not seen; but it must run approximately along the main road from Dippin to Kildonan Post Office.

Good sections of the northerly part of the outcrop can be seen in the Allt Crompucaidh near Largymore ; in the eastern headwater of a small tributary of Glen Ashdale a quarter of a mile east of Torr na Baoileig ; and in the burn immediately west of Torr na Baoileig. At these places the sill rests on shales, marls, and sandstones belonging to the upper division of the New Red Sandstone.

B. PETROGRAPHY

The greater part of the four large sills described above consists of a coarse, analcite-olivine-dolerite, corresponding to the type named *crinanite* by Sir J. S. Flett.[1] Considerable masses, however, are richer in analcite and poorer in olivine, than the normal type, and pass over, therefore, to rocks which are better described as *teschenite*.[1] Further variations are to be found in pegmatitic and aplitic veins, the latter being much richer in analcite and other zeolites than the enclosing rock, whilst the pegmatites differ mainly in their extremely coarse grain. The main type is represented in the Survey collection by specimens from Dippin (6361, 6884), and from the Clauchland Hills (24356, 24456). The teschenitic type is represented by one comparatively fresh rock (6883) and by two considerably altered rocks (6881–2) from Dippin. A gabbroid type poor in analcite is represented by a specimen from the Monamore Burn (25053). No. 24356 shows the mode of occurrence of pockets of pegmatite in the rock, and 25069 represents the aplitic veins intersecting the Clauchland sill.

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[1] 'The Geology of Knapdale, Jura, and North Kintyre,' (Explanation of Sheet 28), *Mem. Geol. Surv.*, 1911, pp. 116–118.

Dr. A. Harker's description of the Dippin rocks (*infra*) gives an excellent idea of the chief microscopical features of the crinanitic and teschenitic types. G.W.T.

The rocks of the Dippin sill have been described (under the name olivine-bearing analcime-diabase) by Corstorphine.[2] They are represented in our collection by five specimens from Dippin and Kildonan.

In hand-specimens the rocks appear as ordinary coarse-textured diabases, dark in colour, but with some variation in the relative proportion of black augite and white felspar, etc. A specimen (6361) gave the specific gravity 2·89. Thin slices show a typical ophitic structure. Olivine is abundant in irregular crystal-grains, sometimes fresh (6361), but usually replaced by green or yellow-brown serpentine. Apatite is always abundant in little prisms about 0·01-inch long, or varying from 0·005 to 0·02 inch. Black iron-ore is also rather plentiful in grains and imperfect or skeletal crystal shapes ; probably magnetite for the most part, but in some cases with outlines suggestive of ilmenite. The felspar is in crystals which give elongated rectangular sections, with Carlsbad and albite twinning. It is labradorite, but not usually of a very basic variety. The ophitic plates of augite show in thin slices the light purple colour and decided pleochroism often seen in the augite of nepheline-dolerites and other rocks rich in alkali, and probably indicating a certain content of soda and titanic acid in the mineral. Rotating over a Nicol's prism, the colour is often seen to change from a purplish or pale claret tint to pale apple-green or pale brownish-yellow. In natural light the ruddy colour is sometimes seen to pass gradually in one crystal into a pale apple-green, which is also pleochroic. Most of the crystals show, though imperfectly, the hour-glass structure which is so generally associated with augite of this kind. Small flakes of brown mica occur rather rarely in the rock.

In addition to the foregoing minerals there are abundant wedge-like and irregularly-shaped spaces occupying the interstices between the felspar and other crystals, and often enclosing numerous needles of apatite. These spaces consist in general of analcite, clear, colourless, feebly refringent, and isotropic, rarely with obscure traces of cleavage. In other cases we find patches of zeolites partly or wholly taking the place of the analcite, forming a yellowish aggregate [1] with more or less pronounced radiate-fibrous structure (6361, etc.) and, if not too fine, showing brilliant interference-colours. Corstorphine identifies natrolite and scolecite: the former might be derived from the analcite, but the latter would have to come from the felspar. In our slices the fibrous zeolites seem clearly to be formed at the expense of the analcite, and are found only in association with other secondary changes in the rock. The analcite itself has all the appearance of an original constituent of the rock. It is most abundant in the freshest specimens, and is there perfectly pellucid and unchanged; in other specimens it is seen in process of conversion to what is probably natrolite. Corstorphine recognizes that the analcite cannot be derived from the felspar, which is often quite fresh, but he supposes it to represent vanished nepheline. While this is possible, there is nothing whatever to indicate the former presence of nepheline, and the supposition seems to be based merely upon reluctance to admit analcite to the rank of an original product from a rock-magma. Various researches on the monchiquites and allied rocks during late years render it difficult to maintain this attitude, and the balance of probability in the case of our rock is decidedly in favour of the view that the analcite is merely the latest product of consolidation of the magma. A.H.

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[1] G. W. Tyrrell, 'The Classification and Age of the Analcite-bearing Igneous Rocks of Scotland,' *Geol. Mag.*, vol. lx., 1923, p. 252.

[2] *Tscherm. Min. Petr. Mitth.*, vol. xiv., 1895, pp. 463–465.

In the analysed rock (24456) the olivine has gone over to serpentine, and the felspars are somewhat zeolitized. It is to be noted that the majority of the rocks are distinctly richer in fresh olivine and poorer in analcite than the typical teschenites of Moravia and the Midland Valley of Scotland. Another mineralogical feature which serves to distinguish the Kainozoic analcite-bearing rocks from both the teschenites and crinanites of Late Palæozoic age on the adjacent mainland, is the almost complete absence of alkali-felspars, and especially of potassic felspars (*see* p. 122).

A good example of a type extremely rich in olivine and approximating to the rock known as *kylite*,[2] is found in a specimen from the shore, a quarter of a mile north-north-west of Clauchlands Point (24356). The augite in this rock is of a stronger purple tint than usual, and has diminished in amount reciprocally with the increase in olivine. The slice is traversed by a thin vein, 2 mm. in width, consisting of analcite and other zeolites (natrolite, scolecite), along with zeolitized felspars, and some red-brown soda-hornblende.

A thicker aplitic vein is represented by a specimen from the shore near Clauchlands Point (25069). Under the microscope this rock shows numerous diversely-arranged labradorite laths, many of which are ophitically enclosed in large plates of pale purplish augite, and the remainder within an abundant groundmass of fresh analcite, There is also some skeletal ilmenite, with which are associated a few scraps of red-brown hornblende, especially where the ore abuts against a crystal of augite. A single crystal of serpentinized olivine is seen enclosed within a plate of augite. The felspars are much corroded by the analcite about their margins and along the cleavage cracks. There are one or two areas of a birefringent zeolite, which is identified as thomsonite, and behaves to the felspars in exactly the same way as the analcite. An analysis of an aplitic vein of this character will be found in Table I.

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[1] Zirkel seems to have observed, but not identified, this aggregate. He also notes quartz-grains (presumably of foreign origin) in a rock from Dippin Head. *Zeits. deuts. geol. Ges.*, vol. xxiii., 1871, p. 36.

[2] G. W. Tyrrell, 'The Late Palæozoic Alkaline Igneous Rocks of the West of Scotland,' *Geol. Mag.*, 1912, pp. 69–80; 120–131.

C. CHEMICAL COMPOSITION

The chemical analysis of an average sample of the Clauchland analcite-olivine-dolerite or crinanite, by Mr. E. G. Radley, is given in Table I., col. 1. The analysis is comparable in general to that of a slightly undersaturated alkaline basalt. The presence of analcite is indicated by the comparatively high values of Na_2O and water. The calculation of the norm shows that about 10 per cent. of olivine, 15 per cent. of pyroxene, and 11 per cent. of iron-ores must be present in this rock ; of the remaining 64 per cent., analcite and other zeolites may be estimated at 10 per cent., leaving acid labradorite (Ab_1An_1) to the amount of 54 per cent.

TABLE I

	1[1]	2	3	A	B	C	D
SiO_2	44·68	46·50	43·95	43·94	44·69	45·57	45·8
Al_2O_3 ..	16·37	22·86	17·60	14·03	14·17	14·95	15·0
Fe_2O_3 ..	4·31	3·30	1·43	1·95	3·35	2·82	3·8
FeO	8·11	4·63	11·89	11·65	10·86	7·35	9·5
MgO	6·59	2·52	6·95	10·46	6·41	6·19	8·2
CaO	8·70	9·50	8·54	8·99	10·28	8·27	9·4
Na_2O ..	3·28	4·53	3·66	2·68	3·64	4·33	2·5
K_2O	·21	·39	·35	·33	2·01	2·16	·5
$H_2O>105°$ ..	1·69	3·25	·82	2·31	2·53	3·93	1·8
$H_2O<105°$ ..	2·99	·80	·94	·85	1·05	·97	·9
TiO_2	2·51	1·30	3·42	2·45	·46	2·41	2·4
P_2O_5	·15	·26	·11	·20	·45	·67	·2
MnO	·32	tr.	·10	·32	·31	·31	·3
CO_2	·06	nt. fd.	nt. fd.	·16	nt. fd.	·18	—
S	—	nt. fd.	tr.	—	—	—	—
FeS_2	nt. fd.	—	—	·04	—	—	—
Fe_7S_8 ..	—	—	—	·06	—	—	—
(Ni, Co)O ..	·05	nt. fd.	nt. fd.	—	—	—	—
BaO	·02	—	—	nt. fd.	tr.	·07	—
Li_2O	nt. fd.	—	—	—	—	—	—
Cr_2O_3 ..	—	—	—	tr.	—	—	—
	100·04	99·84	99·76	100·42	100·21	100·18	100·3

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[1] The Arran analyses are indicated by consecutive numerals. Other analyses tabulated for comparison are indicated by capital letters.

1. (24456, Lab. No. 830). Analcite-olivine-dolerite (crinanite), sill, shore 340 yards N. 9° W. of Clauchlands Point, Arran. *Anal.* E. G. Radley.
2. White aplitic vein in analcite-olivine-dolerite (crinanite), shore, three-sixteenths of a mile N. 9° W. of Clauchlands Point, Arran. *Anal.* W. H. Herdsman.
3. (26383). Crinanite, dyke on shore near Schoolhouse, Whiting Bay, Arran. *Anal.* W. H. Herdsman.

A. (14174). Crinanite or analcite-dolerite, Kainozoic dyke, Slac nan Sgarbh, one mile north of Inver Cottage, Jura. *Anal.* E. G. Radley. Quoted from 'The Geology of Knapdale, Jura, and North Kintyre,' *Mem. Geol. Surv.*, 1911, p. 118.

B. Crinanite, sill cutting 'Permian' lavas, Howford Bridge, Mauchline, Ayrshire. *Anal.* A. Scott. Quoted from G. W. Tyrrell, 'Classification and Age of the Analcite-bearing Igneous Rocks of Scotland,' *Geol. Mag.*, vol. lx., 1923, p. 254.

C. Teschenite. Average of five analyses of the Late Palæozoic teschenites of the Midland Valley of Scotland. Quoted from G. W. Tyrrell, *op. cit. supra.*

D. Average plateau-basalt type of the Kainozoic igneous suite in the West of Scotland. Computed from the analyses given in 'The Tertiary and Post-Tertiary Geology of Mull, etc.', *Mem. Geol. Surv.*, 1924, Table II., p. 15.

Along with the typical crinanite (col. 1), analyses of a white aplitic vein in the Clauchland sill (2), and of a later crinanite dyke from Whiting Bay (3), are given. The chemical composition of the aplitic vein is consonant with its augmentation of analcite and other zeolites, and the dwindling of olivine and pyroxene, as compared with the normal rock. Magnesia and ferrous iron-oxide are considerably lower, whilst alkalies and alumina are higher than in the normal rock. The Whiting Bay dyke is clearly a slightly more basic rock than that of Clauchland, as shown by its lower silica, and higher ferrous iron-oxide and magnesia. This rock is dealt with in more detail on another page (p. 255).

For comparison with the Arran crinanites four analyses, namely, the first-described crinanite of Jura (A); the crinanite sill of Howford Bridge, Mauchline (B); the mean of five analyses of Late Palæozoic teschenites of the Midland Valley of Scotland (C); and the mean of the eight analyses representing the Kainozoic plateau-basalt magma type given in the *Mull Memoir* (D), are tabulated. The type crinanite of Jura is clearly a more mafic rock than that of the Clauchland sill, as is shown by its higher ferrous iron-oxide and magnesia, and its lower alkalies; but in their main features the two analyses are closely comparable. The same remark applies to the analysis of the average plateau-basalt; and it is a justifiable inference that the crinanites represent a hypabyssal facies of the plateau-basalt types of the Western Isles.

A chemical feature common to all the Kainozoic crinanites and related rocks is their relative poverty in potash, which, of course, follows from their lack of potassium-rich minerals. This character, however, serves to distinguish them from the otherwise closely similar crinanites and teschenites of the Late Palæozoic in the Midland Valley of Scotland, as can be seen by comparing the analyses of the Howford Bridge crinanite (B) and the average teschenite (C) with the analyses of the Kainozoic rocks (1, 2, 3, A). G.W.T.

CHAPTER XII

THE KAINOZOIC IGNEOUS ROCKS (*continued*)

QUARTZ-DOLERITE AND RELATED CRAIGNURITIC AND FELSITIC INTRUSIONS

A. INTRODUCTION

WE now deal with a numerous and extensive series of intrusions which consist mainly of a basic or sub-basic rock, quartz-dolerite, and its differentiates in the direction of the intermediate type known as *craignurite*,[1] and finally felsites of related characters. These rocks are to be found mainly in the southern third of the island, and are there widely distributed as sills intruded into the flat-lying or gently-dipping Triassic strata. Dykes, and other masses of transgressive character, are distinctly rare as compared with sills. These sills constitute the main element in the scenery of southern Arran, as they are more resistant to denudation than the soft Triassic strata into which they are intruded, and stand out as scarps with intervening terraces which recall those of the Carboniferous lavas of the mainland. This scarp and terrace topography is particularly well marked in Glen Ashdale (map, Plate II); and the intercalation of sill after sill determines the succession of fine waterfalls which adorn every considerable stream in the south-eastern quadrant of the island.

Glen Ashdale and its headwater, the Allt Dhepin, presents a magnificent section of the quartz-dolerite and related sills, and it is therefore proposed to describe this section first as the typical exposure. The sills to the north and south of Glen Ashdale will then be treated. After this will be described in succession the series of large intrusive masses centred about Tighvein, 3½ miles west of Whiting Bay, and extending northward through Sguiler, The Ross, Cnoc Dubh, and the Sheans, to the Brodick district; and the intrusions of Auchareoch, Auchenhew, Levencorroch, and Kildonan, which are probably southward extensions of the Tighvein masses. Finally, the intrusions in the valley, and at the head, of the Sliddery Water, and a series of western masses, Ballygown, Beinn Tarsuinn, and Tormusk, situated to the east of Blackwaterfoot, will be dealt with.

The intrusions treated in this chapter are remarkable for the abundance of composite sills, and of the phenomena of xenolithic enclosure and hybridization along interior contacts, which they present. In general three petrographic varieties are distinguishable in the field; (1) a dark grey, or bluish-grey, medium-grained to fine-grained dolerite, passing to basaltic types towards their contacts and in the smaller masses—' blue basalt ' was the appropriate field term utilized for these rocks ; (2) a light bluish-grey to ash-grey, fine-grained to compact rock, obviously more acid than the 'blue basalts,'—this type is identical in composition with the craignurites of Mull ;[1] (3) a light grey or yellowish to white rock, granophyric to felsitic in texture, in which minute blebs of quartz can usually be distinguished. These types, while broadly recognizable in the field, are nevertheless connected by many intermediate varieties, and form a continuous petrographic series from dolerite to granophyre, or basalt to felsite (p. 141). In the majority of cases the felsitic rocks are the latest injections, and xenolithic enclosure and hybridization of dark basic fragments included within a matrix of felsitic composition is a common feature. In some cases interior contacts are marked by the xenolithic enclosure of one textural or compositional variety of basaltic or intermediate rock by another.

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[1] *See* Note 3, p. 141.

B. FIELD-RELATIONS

1. *The Glen Ashdale–Allt Dhepin Section* (*Fig.* 11)

The first and lowermost sill is met with at the large waterfall (p. 4) in Glenashdale Wood, one mile from the sea. The lower contact is well seen in the face of the upper fall, and along the escarpments on both the north and south sides of the gorge. The sill rests on horizontal baked sandstones. The basal rock is a compact, banded, pink and grey quartz-felsite which, 5 feet up, remains substantially the same rock, but becomes a trifle coarser in grain. At 10 to 12 feet above the base the coarse felsite passes rapidly into a fine-grained, vesicular 'blue basalt.' Unfortunately no visible feature marks the change on the weathered surface, and the section becomes very inaccessible at this critical point. The 'blue basalt'

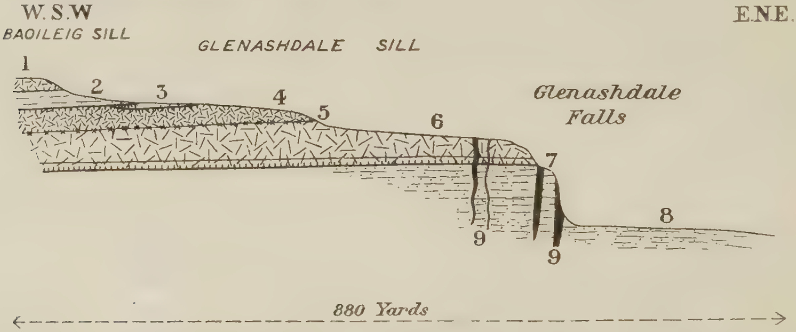

FIG. 11.—*Section along Glen Ashdale from the Falls to confluence with Baoileig Burn.*

1. *Quartz-dolerite* ; 2. *Shales and sandstones* ; 3. *Felsitic margin with intercalation of sandstone* ; 4. *Upper quartz-dolerite* ; 5. *Xenolithic interior contact* ; 6. *Lower quartz-dolerite* ; 7. *Felsitic margin* ; 8. *New Red Sandstone* ; 9. *Basalt dykes.*

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[1] 'The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1924, p. 224. In later footnotes referred to as *Mull Memoir.*

becomes coarser as it is traced upward ; and at the top of the fall, as well as for some distance above it, the rock is a medium-grained quartz-dolerite, which is intersected by several thin, irregular, basaltic dykes, and by acid segregation veins.

Farther up the stream the grain-size begins to diminish until, a few yards within the western boundary of the wood, there is encountered a band of dense 'blue basalt,' containing numerous, faintly-defined, darker xenoliths. This rock rapidly becomes coarser to the west, and forms a strong ledge and a waterfall just within the wood. One hundred and fifty yards above the wood the sill is again exposed. The rock is here slabby, and is deeply weathered to a buff colour, but the blocks are blue-hearted. It is a rather more felspathic type of quartz-dolerite than that of other parts of the composite sill. A spherulitic felsite, similar to that at the lower contact, follows, but with no traceable passage. The top of the sill is seen at the bend a twelfth of a mile above Glenashdale Wood, passing under 2 feet of sandstone, above which comes a small felsitic protrusion, not more than 4 feet thick, although the actual junction with the sediments is not exposed. The uppermost 2 inches of this intrusion are composed of a black, banded, pitchstone-like rock (24874). From this point to the confluence of the Allt Dhepin[1] with its tributary the Baoileig Burn, the solid rock is concealed beneath a small patch of alluvium.

The Glenashdale sill is thus composite, and consists of four main parts, from above downwards as follows (*see* Section, Fig. 11) :

1. The upper felsite, with intercalation of sediment.
2. Felspathic quartz-dolerite or craignurite.
3. The main quartz-dolerite.
4. The lower felsite.

There is a xenolithic band between 2 and 3 indicating an interior contact. The order of injection still requires some further elucidation. It appears probable, however, that the marginal felsite was first intruded, and that after cooling it was split centrally by the main quartz-dolerite injection. While the latter was still hot it was penetrated by a further protrusion of slightly more acid material, which caught up fragments of the basaltic contact rock, and included them in its marginal parts as xenoliths.

The next sill in upward succession first appears at the foot of the Baoileig Burn, and may therefore be referred to as the Baoileig Sill. Its base can be examined in the gorge of the Allt Dhepin extending from the confluence of the Baoileig Burn to a waterfall 200 yards farther west. At the former locality the rock is finely columnar, and rests on horizontal red sandstones and marls. The upper contact is seen at the top of the waterfall. The rock is fine grained throughout, becoming very dense at the contacts, and is in general light grey or blue-grey in colour. It carries sporadic, slender, white, phenocrysts of felspar. The composition is that of a felsite of craignuritic affinities. About the middle of the sill is a band with flow-elongated vesicles. The thickness is estimated at 40 feet.

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[1] The name Allt Dhepin applies to the stream in Glen Ashdale above Glenashdale Wood. Within and below the wood it is called the Glenashdale Burn. See six-inch quarter-sheet, Buteshire, 255 S.W.

For 150 yards the bed of the burn is now occupied by horizontal red sandstones and marls. Then begins the outcrop of the great Garbad quartz-dolerite sill (so-called from Cnoc na Garbad to the south), which occupies the burn and its banks for nearly a mile. The Garbad mass contains numerous, thin, lenticular intercalations of sediments; or, in other words, from the focal mass of Cnoc na Garbad, there are thrown off numerous subsidiary offshoots which thin out among the sediments to the east and west.

At the waterfall in the Allt Dhepin (100 yards E.S.E. of the 539 feet O.D.) is seen the easternmost of these offshoots. At the fall it transgresses sharply across the sandstones, which are much disturbed and faulted. This sill clearly thins out to the east amongst the sediments; to the west and north-west it appears to join up with the main mass of the Garbad sill. It can be traced up to the waterfall near 539 feet O.D., where a small patch of sediments is brought in by a fault throwing 6 feet to the north-west.

Above this point there is a more extensive intercalation of sediments in the bed of the burn, with cliffs of ' blue basalt ' on either side. The main central part of the Garbad mass is reached in a remarkable dyke-gorge S.E. of 634 feet O.D., east of Cnoc an Fheidh (873 feet O. D.). The rock is here a coarse quartz-dolerite (24459) which has been selected for analysis (p. 147).

From this point onward the Allt Dhepin section is penetrated by an extraordinary number of dykes which run mostly north-west and north-north-west (Fig. 12). A small waterfall at the north-western end of the dyke-gorge mentioned above is caused by a dyke along a small fault throwing to the west. Above this point there is a fine section in the red sandstones and marls of the upper part of the New Red Sandstone, with the ' blue basalt ' seen at the top of the cliff (634 feet O.D.). This condition continues up to and beyond the sharp loop in the burn, south of 739 O.D. No less than six dykes intersect the northern limb of the loop. The ' blue basalt ' descends to the bed of the burn and occupies the channel for about 100 yards at 739 feet O.D. Its base then rises again, leaving the underlying sediments, as before, occupying the bed of the stream.

A section in a tributary flowing east and entering the Allt Dhepin to the north of Cnoc an Fheidh illustrates the multiple character of the Garbad mass (Fig. 12).

A small fault running north-west to south-east at the bend in the burn below 786 feet O.D. at length brings in a sill (the Allt Dhepin sill) on a higher horizon than the Garbad mass. This sill is well exposed at the large waterfall near 786 feet O.D., where it is underlain by red sandstones and marls. It consists of an ash-grey felsite of craignuritic affinities; a rock collected from the top of the fall has been analysed (24458, *see* p. 147). The sill is first seen in a tributary gully entering the Allt Dhepin from the east opposite 739 feet O.D. (Fig. 13). This rock occupies the bed of the Allt Dhepin up to the bend near 824 feet O.D., where the lower contact is again seen. The sediments now continue for some distance up the burn, occupying its floor, while grey felsitic rock, probably the same as that of the Allt Dhepin sill, forms the walls of the gorge. A well-marked north-west to south-east fault throwing 10 feet to the south-west is seen just above the confluence of a tributary from the north ;

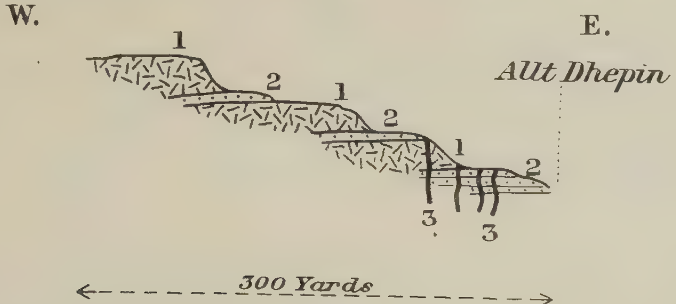


FIG. 12.—*Section along tributary to Allt Dhepin, north of Cnoc an Fheidh, showing intercalations of sandstone* (2) *within Garbad quartz-dolerite sill* (1), *and basaltic dykes* (3). *Vertical scale much exaggerated.*

and a dyke, 12 feet wide, of grey felsite with dark xenoliths, occurs at the foot of a waterfall 250 yards E.S.E. of 982 feet O.D. Above this point the top of the sill is seen, with a fine section of overlying sediments. It consists of a flow-banded, yellow or white, felsitic rock. From this point up to 1118 feet O.D., half a mile east of the summit of Tighvein (1497 feet O.D.) exposures of grey felsitic rocks are intermittently seen, which may belong to a sill on a yet higher horizon than the Allt Dhepin sill, and may be identical with the widespread sheet which caps the plateau around Loch na Leirg.

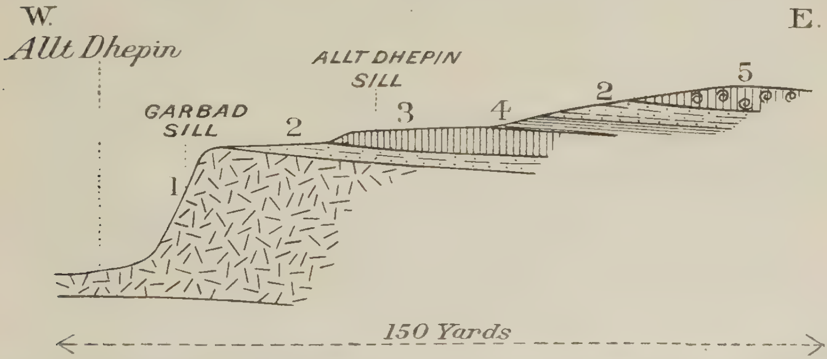


FIG. 13.—*Section in a gully entering the Allt Dhcpin from the east, opposite 739 feet O.D.*

1. *Quartz-dolerite ;* 2. *Sandstone ;* 3. *Craignurite-felsite ;* 4. *Marls ;* 5. *Sill of spherulitic felsite. Vertical scale exaggerated.*

The Allt Dhepin section thus reveals at least five large sills and sill-complexes composed of rocks ranging from quartz-dolerite to felsite of craignuritic type as follows :—

	Approximate Height of Base. Ft.	Estimated Maximum Thickness. Ft.
5. Uppermost sill—craignuritic felsite. (Loch na Leirg sill)	1010	100
4. Allt Dhepin sill—craignuritic felsite	770	210
3. Garbad sill—quartz-dolerite	500	250
2. Baoileig sill—felsite and quartz-dolerite of craignuritic affinities	420	40
1. Glenashdale sill—quartz-dolerite and felsite composite sill	190	210

As the strata are nearly horizontal it is comparatively easy to estimate the maximum thicknesses of the respective sills. Still higher in the succession are the intrusions which form part of the Tighvein complex which is described later (p. 133) ; and in the coastal regions of Whiting Bay and at Largybeg there are one or two sills on a lower horizon than the Glenashdale sill (p. 132).

2. *Sections North of Glen Ashdale*

A series of five tributaries to the Glenashdale Burn provides the means of tracing the main sills to the north. These burns are the Allt Garbh which drains Loch na Leirg ; and then, to the south-west, a series of four unnamed burns which have been designated A, B, C, and D, respectively, from north-east to south-west (*see* Plate II). Burn D, which occupies a gorge on the east side of Cnoc Mòr (867 feet O.D.), loses itself in a bog before reaching the main stream.

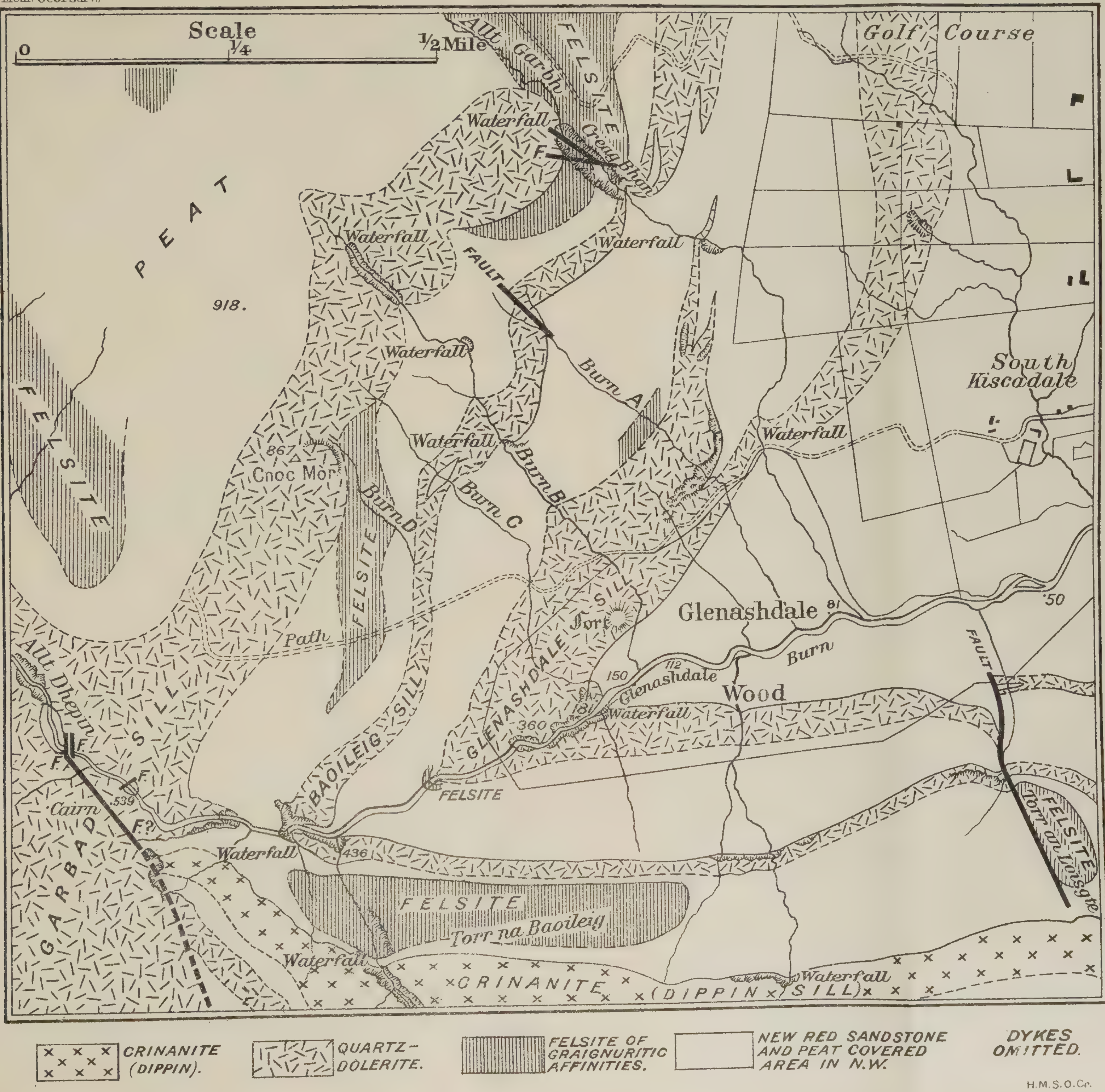
The Glenashdale sill forms a massive outcrop following the northern boundary of Glenashdale Wood. There is a fine glaciated exposure where Burn B crosses the moorland track on the north side of the wood. The sill also forms a range of cliffs crossing Burn A. At this point the sill bifurcates ; a northern branch, continuously thinning, causes a small waterfall in the Allt Garbh, below Creag Bhan, and then fades out among the sediments. The branching here may be taken as confirmation of the view that the sill is multiple. The main branch, however, crosses the Allt Garbh at the northern corner of Glenashdale Wood (*see* map, Plate II), the exposures here showing dark xenoliths, and then continues to the north across the golf course, following the contours of Borrach (869 feet O.D.). Good sections are exposed in the Allt Ceirde and in a burn to the south. In the Allt Ceirde a felsitic rock appears at both contacts.

One or two 'blue basalt' sills, on lower horizons than the Glenashdale sill, are exposed in the Cal Burn at North Kiscadale, Whiting Bay.

The Baoileig sill can likewise be traced across Burns C, B, and A, and crosses the Allt Garbh at the lower end of the gorge known as Creag Bhan. Its course between the Glenashdale Burn and

GEOLOGICAL MAP OF THE REGION AROUND GLENASHDALE, WHITING BAY.

Plate II.



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Burn D, however, is rather uncertain. In Burn C it encloses a lenticle of sediments, and near Burn B its outcrop is broken by a small north-west to south-east fault. North of the Allt Garbh it throws off at least two branches which die out amongst the sediments.

The Garbad sill can be traced from the Allt Dhepin north-westwards across the moor by means of a series of scattered exposures. Good sections of it are exposed on Cnoc Mòr, and in a gorge at the head of Burn B (Fig. 6, p. 88). The sill ends off bluntly and abruptly against felsite near Creag Bhan. A plan of the exposures in Creag Bhan is given in Fig. 14.

Between the outcrops of the Baoileig and Garbad sills there appears on both sides of Glen Ashdale a series of disconnected masses of spherulitic felsite or granophyre. These are all thick and massive intrusions which have the habit of ending off very abruptly. One is seen in the Creag Bhan section (Fig. 14). This mass fades out to the south-west before Burn A is reached. A second intrusion appears below Cnoc Mòr, and is well exposed in the gorge of Burn D. It ends off abruptly to the north as a thin mass of platy felsite at the head of Burn C (Plate II). To the south it crosses the moor track, and is then lost to sight.

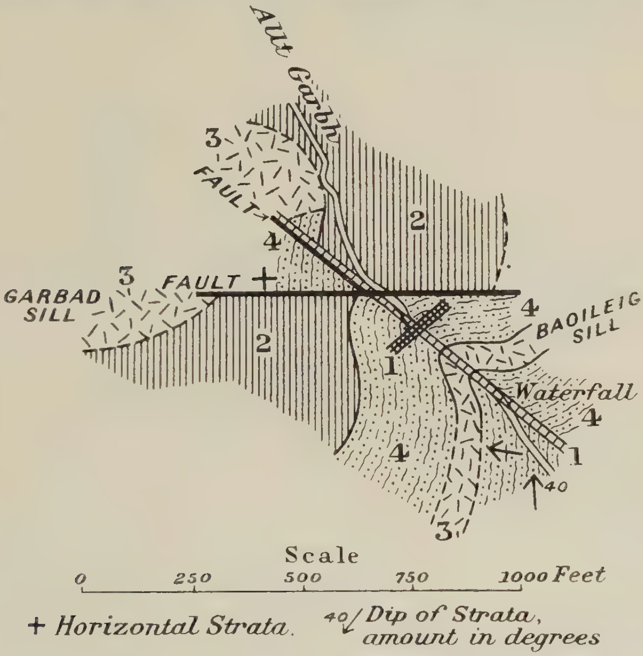

FIG. 14.—*Plan of exposures in Creag Bhan, Allt Garbh, Whiting Bay.*

1. *Basalt dyke*; 2. *Felsite sill*; 3. *Quartz-dolerite sills*; 4. *Triassic sediments.*

Very little is known as to the extent of the Allt Dhepin sill on the eastern side of the valley. It extends as far south as the gully near 739 feet O.D. (Fig. 13), but appears to wedge out farther south. On a higher horizon a thick mass of spherulitic felsite appears. A poor section is exposed in the above-mentioned gully (Fig. 13), and the sill can be traced southward by numerous large blocks on the moor surface (Plate II, felsite mass on western margin). This intrusion is probably the same as that which caps the plateau around Loch na Leirg, near which there are many exposures. Similar rocks are seen in fragmentary exposures in many places on the moor, notably near 972 feet O.D. (Plate II), and in the region half a mile south-west of Urie Loch. A columnar sill of felsite is to be seen in the Kingscross Burn at Sloc Ruaridh, half a mile N.N.W. of Loch na Leirg, but this seems to be on a somewhat lower horizon than the Loch na Leirg mass.

3. *Sections South of Glen Ashdale*

The various sills cause well-defined scarp and terrace topography on both sides of Glen Ashdale, but particularly so on the south side (Plate II). They can therefore be mapped with considerable facility. The Glen Ashdale sill continues as a well-marked cliff through the southern part of Glenashdale Wood, until it reaches a N.N.W.–S.S.E. fault which passes by Torr an Loisgte (*see* map, Plate II). It is here offset to the south, and is split by an intercalation of sediments. From this point the outcrop curves round to the south, passes below the cairns known as the Giants' Graves, and exhibits a good section in the Allt Crompucaidh. Both the sill and the adjacent sediments are here much disturbed, and dip at 60° to the west (Fig. 15). The scarp can now be traced from the Allt Crompucaidh to Largybeg, running in a general south-south-east direction; and, although there are no intervening exposures or features, it is probable that a small sill of 'blue basalt' at Port na Gaillin, a sixth of a mile south-west of Largybeg Point, is its shoreward termination. The sill is here only a few feet thick as compared with over 200 feet in the Glen Ashdale section. It is not only thinning out to the east, but it has also lost the felsitic marginal facies, which are not seen from Glen Ashdale eastwards. This eastward thinning, which appears to be general in the sills of the quartz-dolerite suite, is in marked contrast to the behaviour of the crinanite sills (p. 113).

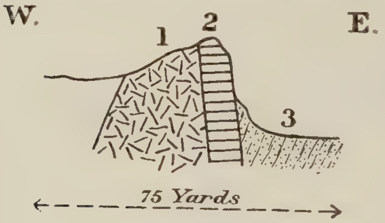

FIG. 15.—*Section in the Allt Crompucaidh, Largymeanoch, Whiting Bay.*

1. *Quartz-dolerite (Glenashdale Sill); 2. Basalt dyke; 3. New Red Sandstone. Vertical scale exaggerated.*

The Baoileig sill forms an equally well-marked escarpment and terrace which, on the north flank of Torr na Baoileig, makes a narrow ledge just below the steep escarpment marking the outcrop of the

Baoileig felsite. The Baoileig sill is cut off and offset by the Torr an Loisgte fault, and continues as a small ledge and scarp around the base of Torr an Loisgte, where it turns south and passes above the Giants' Graves. A good section is exposed in the southern headwater of the Allt Crompucaidh, where the sill is 15 to 20 feet in thickness, and is dipping along with the adjacent sediments at 30° to the W.S.W. (Fig. 16). The scarp fades out below the Stone Circle on Bealach Gaothar, and the sill cannot be traced any farther south. A recent small landslide on the road south of Largybeg shows a 6-foot sill of ' blue basalt ' just below the scarp of the Dippin crinanite. This is in all probability the Baoileig sill, which, like the Glenashdale sill, is thinning towards the east.

Between the Baoileig sill and the scarp of the Dippin crinanite there occur two masses of felsite precisely similar to those occurring on the north side of Glen Ashdale along the same horizon. The Torr na Baoileig mass consists of a coarse spherulitic felsite or granophyre, and is well exposed in the Baoileig Burn. To the east it ends off very abruptly about half a mile west of Torr an Loisgte. The second mass forms the hill of Torr an Loisgte, which is a prominent scenic feature in the view from Whiting Bay to the south. The rock is a spherulitic felsite which weathers with a minutely-nodular surface. On the west side the intrusion appears to be bounded by the Torr an Loisgte fault; on the east it rises as a short abrupt scarp above the Baoileig sill (*see* map, Plate II).

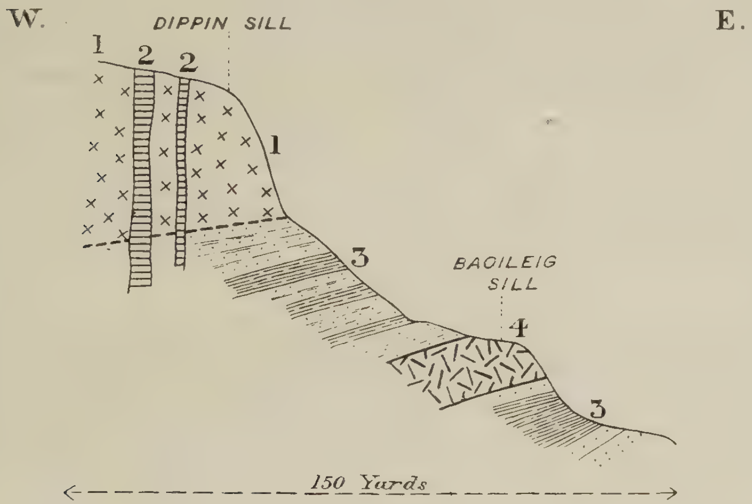

FIG. 16.—*Section in the southern headwater of the Allt Crompucaidh, Largymeanoch, Whiting Bay.*

1. *Dippin crinanite sill*; 2. *N.N.W. Basalt dykes*; 3. *Red Sandstones and shaly marls (New Red Sandstone)*; 4. *Baoileig quartz-dolerite sill. Vertical scale exaggerated.*

The great Garbad sill which, on the south side of the Allt Dhepin, spreads around Loch Garbad as centre, is a very thick mass of coarse quartz-dolerite. It is well exposed in many places, notably around Loch Garbad, along its eastern scarp, and at Cnoc na Garbad (959 feet O.D.). At Loch Garbad the rock carries many xenoliths of fine-grained 'blue basalt,' and it may therefore be conjectured that there is an interior contact at this locality.

The most notable feature of the Garbad sill is the extraordinary straight scarp running N.N.W. to S.S.E., which bounds it on the eastern side (*see* One-inch Geological Map, Arran, 1910). This scarp runs from the Allt Dhepin to Cnoc na Garbad, a distance of one mile. It is in line with the upper part of the Allt Dhepin, and it coincides in direction with the majority of the dykes of this region, and with many small faults. The scarp of the Dippin crinanite appears to be cut off abruptly against it (*see* map, Plate II). The feature is interpreted as marking the line of a large fracture, which may or may not have been a fault. This fracture is believed to have served as the focus for the irruption of the Garbad quartz-dolerite, and possibly for the other quartz-dolerite sills of the neighbourhood. According to this view the quartz-dolerite magma rose up along this fissure, and was injected mainly to the west; but several smaller protrusions were thrown off to the east, as, for example, the one that forms a scarp immediately above the Dippin crinanite (Plate II, south-west corner), and the one that occurs in the Allt Dhepin immediately west of the Baoileig sill (p. 126).

On the north side of Cnoc na Comhairle (913 feet O.D.), a flat-topped hill three-quarters of a mile south-east of Torr na Baoileig, three sills of 'blue basalt' may be traced above the scarp of the Dippin crinanite. The lowermost is thin and impersistent, and shows a peculiar vitreous facies at a point a quarter of a mile S.S.W. of Torr an Loisgte; the second is rather thicker, but fades out rapidly both to the east and west; the third and highest is much more persistent, extending from the Garbad escarpment round the summit of Cnoc na Comhairle to Torr na Cloiche. The actual summit of the hill is composed of sandstone.

On the south side of Glen Ashdale, as on the north, one or two 'blue basalt' sills are found at horizons lower than that of the Glenashdale sill. One such, for example, is found in the section across Largybeg Point (Fig. 7, p. 90), and is 15 feet thick. A massive dyke of craignuritic felsite hading north-east is found at the northern end of the section.

On a still lower horizon is the sill which forms Creag Dubh, the southern horn of Whiting Bay. The lower contact of this sill is exposed at low tide, and is seen to rest on sandstone dipping W.S.W. at 20°. The thickness of the mass is estimated at 30 feet. The rock consists of an acid quartz-dolerite. On one visit a glomeroporphyritic segregation of yellow felspar, 6 inches in diameter, and elliptical in shape, was seen on the seaward side of the crag.

4. *Tighvein, Sguiler, The Ross, Cnoc Dubh, The Sheans, and the Brodick Area*

Tighvein.—The masses of igneous rock occuping these localities form a complex and connected series of intrusions extending northward from Tighvein (1497 feet O.D.), situated about 3 miles west of Whiting Bay, to the neighbourhood of Brodick. On the One-inch Geological Map of Arran (1910) the exposures on Tighvein are mapped in the form of an ellipse with its long axis in a north to south direction, which suggested the possibility of a ring-dyke complex in this neighbourhood. In spite of the fact that the exposures are poor and disconnected, owing to the deep covering of peat on the Tighvein plateau, the writer is inclined to believe that the intrusions are mainly concordant in character, and are sills injected on a higher horizon than those of the Glen Ashdale and Allt Dhepin region. The writer has only so far studied the eastern half of the Tighvein complex, and it may be that the sections on the west and south will provide better evidence as to the disposition of the intrusive masses.

A good section on the south-east side of Tighvein is provided at the head of the Allt nan Clach, one of the headwaters of the Kilmory Burn. A traverse of the little gorge which extends from the Kilmory to Lamlash track to the summit of the plateau gives the section shown in Fig. 17. The lowermost sill is a grey, acid, craignuritic felsite, which rests on Triassic marls and sandstones and has a flow-vesiculated base. It is almost certainly on a higher horizon than the sill occupying the summit of the Loch na Leirg plateau. The sediments are dipping to the south-west, although as this section is along the strike, they are here apparently horizontal. The second sill is a ‘ blue basalt ’ or fine-grained quartz-dolerite, and contains xenoliths of quartzite. Its base is well seen, but its upper part is concealed beneath peat. A fragmentary exposure of ‘ grey basalt’ in the peat north-west of the pitchstone dyke, may represent a third sill or the upper part of the second sill. Above the pitchstone the ground rises in an ill-defined scarp, and an exposure of coarse, rotted, gabbroid rock (augite-diorite) is seen. About 300 yards north-north-west of this exposure is a rough rocky knoll composed of the same rock.

From this point to the summit of Tighvein the ground is covered with peat, on the surface of which are strewn numerous blocks of microgranite. This rock occupies the area practically to the summit ; but the top of Tighvein itself, and of an isolated knoll to the south-west, consists again of augite-diorite. This rock is cut by numerous irregular veins of an acid rock. A ridge near 1490 feet O.D. provides the best exposure of the microgranite. This rock appears to form the summit of the plateau, and falls to the east in a fairly well defined scarp on to the terrace of the lower augite-diorite. No contacts are seen, and it is therefore difficult to decide whether we are dealing with sills or broad ring dykes. The spreading of the outcrops of the augite-diorite to the north and to the south-west, however, seems to indicate that these masses should be interpreted as sills. The upper part of the section (Fig. 17) therefore, is drawn according to this view.

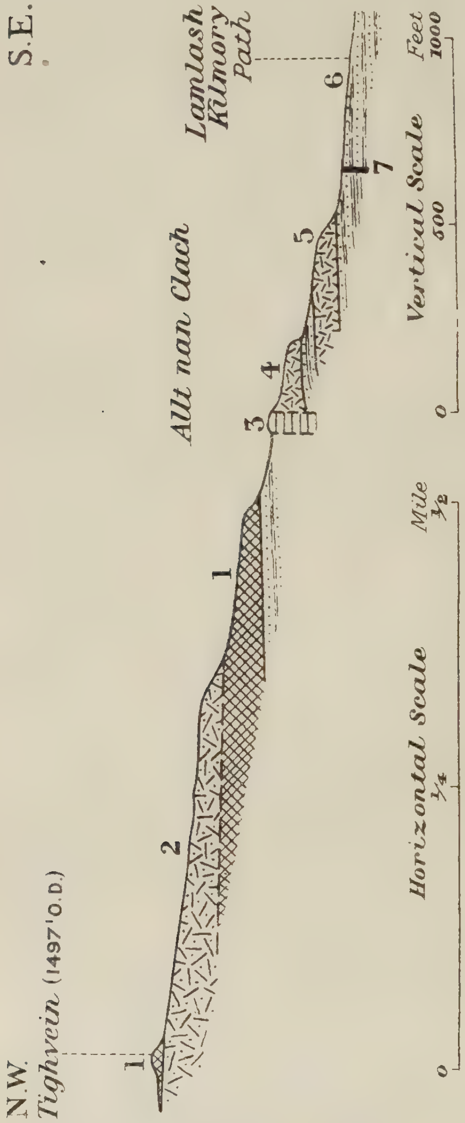

FIG. 17.—*Section from Tighvein to head of the Allt nan Clach.*

1. *Augite-diorite* ; 2. *Micro-granite* ; 3. *Pitchstone* ; 4. *Quartz-dolerite* ; 5. *Craignurite* ; 6. *Triassic sediments* ; 7. *Basaltic dyke.*

A little western headwater of the Allt Dhepin, descending from 1490 feet O.D. east of the summit of Tighvein, provides a section on the eastern face of the hill (Fig. 18). The lowermost sill is a typical 'blue basalt.' On a higher horizon there is a slabby, whitish, acid sill, which may be the same as the lowermost sill of the Allt nan Clach section. Augite-diorite and microgranite are again seen at the summit of the plateau.

Between this point and Urie Loch there are many large blocks and an exposure of a coarse, rotted, gabbroid augite-diorite. The boundary of this rock, marked by small crags, sweeps round the head of the Allt Dhepin immediately south and south-east of Urie Loch; and in a crag on the eastern side of the valley the coarse gabbroid rock contains xenoliths of a dark, fine-grained, 'blue basalt,' and the whole exposure is traversed by irregular veins of granophyric rock.

Xenolithic rocks of the same character, with but slight variations in texture, are to be seen in the exposures around Urie Loch. A little intrusive boss of spherulitic felsite, probably a devitrified pitchstone (p. 215), breaks through the augite-diorite on the south shore of the loch; and a dyke-like mass of the same character borders the loch close by. A dyke of fine-grained quartz-dolerite with angular xenoliths of still more fine-grained basalt, occurs on the north-east shore of the loch.

Sguiler.—The xenolithic augite-diorite may be traced at intervals through the peat in the region between Urie Loch and the summit of Sguiler (1332 feet O.D.), which overlooks Monamore Glen. The base of the sill shows an extraordinary development of xenolithic enclosure, the fine-grained basaltic rock having apparently been shattered, and then intimately interpenetrated by a more acid rock. This phenomenon is discussed at greater length in connection with the Sheans (p. 136). On the peat-covered terrace immediately to the south of the summit of Sguiler numerous fragments of felsite are to be seen, which are interpreted as belonging to a sill injected just below the base of the Sguiler mass. From Sguiler the boundary of the basic sill runs south-east to Creag na h'Ennie, and thence to east of Urie Loch.

The Ross.—The Ross is the prominent hill (992 feet) which rises on the north side of Monamore Glen, between the Monamore and Benlister valleys. The summit of The Ross consists of a coarse gabbroid rock. On the south side of the hill, the base of the sill, consisting of fine-grained dolerite near the texture of 'blue basalt,' is seen. It is injected by fine-grained veins and thin sills of basalt, with very dense, almost tachylytic, margins. These injections range from a fraction of an inch to about a foot in thickness. Near the western end of the outcrop on the south side of The Ross, intercalations of sandstone, baked to hard white quartzite, make their appearance, and cause the marked banding on the face of the cliff as seen from the Ross Road. This banding is parallel to the general easterly dip of the sill. At the western end of the sill there is also a marked primary banding in light and dark, coarser and finer, more acid and more basic, bands.

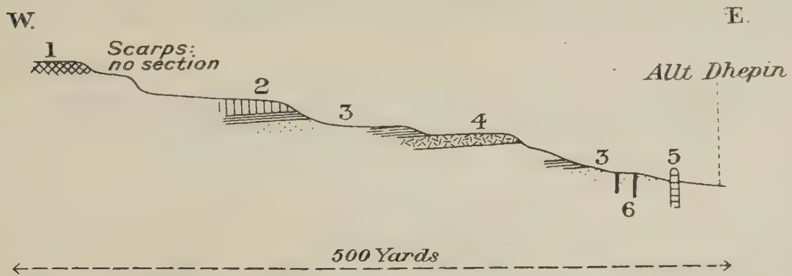

FIG. 18.—*Section in western headwater cf the Allt Dhepin, one-third of a mile south of Urie Loch.*

1. *Augite-diorite ;* 2. *Craignurite-felsite sill ;* 3. *Red marls and sandstone ;* 4. *Quartz-dolerite sill ;* 5. *Quartz-porphyry dyke ;* 6. *Basaltic dykes. Vertical scale exaggerated.*

The nature of the sill of The Ross is doubtful. The Survey possesses no specimens, and those in the Glasgow University collection are much decomposed. The thin sections are puzzling. There is very little free quartz, and all the ferro-magnesian minerals have gone over to chlorite. Without fresh material it is hard to say whether this mass is really a continuation of the Monamore crinanite (as it is mapped on the One-inch Geological Map), or a member of the quartz-dolerite suite.

A typical ' blue basalt ' dyke, 12 feet wide, and running in a north-north-west direction, cuts the base of the Ross sill. This rock is a quartz-basalt obviously belonging to the oversaturated suite. It weathers with a whitish crust, and is mapped as a felsite on the One-inch Geological Map (1910). It may perhaps be regarded as evidence for the view that the sill of The Ross really represents the Monamore crinanite.

Cnoc Dubh (1003 feet O.D.) is the summit of the plateau north of the Benlister Burn. It is occupied by an ill-defined and poorly-exposed doleritic intrusion, of which the small detached masses to the east and north-west (including the Sheans) appear to be outliers (*see* One-inch Geological Map). The only specimen collected from this mass (25048), from the western side of the hill, is a quartz-basalt with porphyritic plagioclase felspar and a number of xenocrysts of alkali-felspar.

The Sheans.—The Sheans consist of three abrupt rocky hills rising on the edge of the plateau to the south and south-east of Glen Dubh, about 2¾ miles south-west of Brodick Pier. The south-eastern hill shows a compact grey basaltic rock at the foot of the slope. On its summit, however, there is a porphyritic dolerite, intersected by fine-grained acid veins which weather as whitish raised reticulations on the surfaces of the exposures. The central Shean is separated from the above by a deep peat-filled depression. This hill has a long protrusion to the south. At the south-eastern end of the main knoll soft red sandstone, in a horizontal attitude, occurs at the base of the slope, clearly passing beneath the dolerite, and establishing the sill character of the intrusion. The rock is of the same general character as that of the south-eastern hill, but is only sparingly porphyritic. It shows the most extraordinary brecciation, the separated angular or partially-rounded fragments of dark-coloured and rather compact basalt being enveloped in a more acid type which weathers light grey or white. The fragments are mainly between 2 and 6 inches in greatest diameter, and are generally somewhat rounded as if solutional effects had taken place between the xenoliths and the matrix. In freshly-broken material the lines of junction between fragments and matrix are often hard to distinguish, although they are brought out most spectacularly by weathering. The best place to collect specimens is slightly below the summit of the hill on the western side. Occasionally the light acid material forms stratiform bands in the dark rock.

It seems perfectly clear from the exposures that the dark basalt was shattered when solid, and that the acid material then filled up the intervening spaces, and was hot enough to produce some solutional and hybridization effects. The whole thickness of the tabular mass, estimated at 50 feet, appears to have been involved in this shattering and veining process; and it appears possible to trace increasing grain-size in the xenoliths from the base of the hill to the top, showing that the brecciation occurred within a normally-cooled intrusive mass.

Although there is a peaty depression between the central and northern hills of the Sheans, the exposures show that the sill is really continuous between the two hills. On the north side of the northern hill the same xenolithic rock is seen as on the central hill, but there is apparently a greater quantity of acid matrix. The base of the intrusion is not actually seen, but it is marked by the occurrence of a narrow terrace of hard, white, carious sandstone.

Brodick Area.—A mile east-north-east of the Sheans, and about 2 miles south-south-west of Brodick, there are many small sills exposed in the headwaters of the Lag a' Bheith. These are mainly of felsitic composition. Their thickness rarely exceeds 20 feet. The best exposure is in a small road-metal quarry situated where the old moor road crosses the easternmost headwater, about a quarter of a mile west-south-west of the Stone Circle near the fourth milestone on the Brodick–Lamlash road. This is in a fresh-looking, light blue-grey, craignuritic felsite (25059), which contains sparse, coarse-grained segregations (25076). The main headwater, which descends from a point north of Cnoc Dubh, shows no fewer than six thin sills from where it is crossed by the old moor track, to its confluence with the main burn. The uppermost of these is probably a devitrified pitchstone (25060–1), one of the intermediate or basic types which belong to the quartz-dolerite–craignurite-felsite suite.

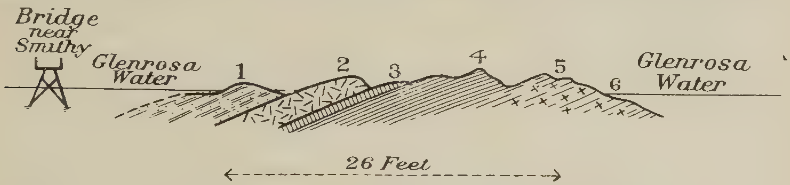

FIG. 19.—*Section across composite sill in the Glenrosa Water at bridge near Smithy, Brodick.*

1. *Fissile sandstone*; 2. *Quartz-basalt*; 3. *Dark top of felsite*; 4. *Banded felsite*; 5. *Xenolithic felsite*; 6. *Base of sill, concealed.*

The composite sill described by Dr. A. Scott [1] from Glen Cloy, Brodick, belongs to the series under description. The greater part of it is a dark-grey felsitic rock which has a spherulitic appearance. Towards the top of the sill this rock is overlain by a black, flinty, pitchstone material, with a sharp junction between the two parts. The total thickness of the mass is estimated at 12 feet.

An interesting section of a small composite sill belonging to this suite is seen in the Rosa Water at Rosaburn Bridge, near the Smithy, Brodick. The section is as shown in Fig. 19. Below a fissile banded sandstone dipping 35° to the south-east, there occurs a stratiform quartz-basalt intrusion about 4 feet thick. This is followed downwards by spherulitic felsite, with a sharp junction against the basalt. The felsite is dark at the top for a foot or so; then comes a banded layer; and finally, within the lower part of the mass, appears a strongly xenolithic band, with dark, angular to rounded fragments of basaltic composition up to one inch in diameter (7538). The base of the mass is not seen, but it probably consists of the complementary basalt member of a triple composite sill, whence were doubtless derived the above xenoliths. The visible thickness is 15 feet, and the total thickness is estimated to be 20 feet.

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[1] 'A Composite Sill in Glen Cloy, Arran,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 140–150.

5. *Auchareoch, Auchenhew, Levencorroch, and the Kildonan Area*

The Auchareoch, Auchenhew, and Levencorroch masses appear to represent the horizons of the Tighvein complex in a southward direction. The Kildonan intrusions, however, are injected on a horizon below that of the Dippin crinanite, and are therefore on the same stratigraphic level as the Baoileig and Glenashdale sills of the Whiting Bay district.

Little is known as to the field-relations of the three large masses above mentioned. They all consist of a coarse quartz-dolerite. The Auchareoch sill is well exposed in tributaries of the Kilmory Water near the farm of Auchareoch, but its surface and its boundaries are largely obscured by peat. Auchenhew and Levencorroch Hills are capped by what appears to be the same sill of quartz-dolerite, the outcrop of which has been severed into two parts by the deep gorge of the Levencorroch Burn. The Auchenhew mass is represented by three specimens in the Survey collection (6885–7).

An interesting section of a small 6-foot sill of ‘blue basalt’ on a lower horizon than the Auchenhew–Levencorroch mass is exposed in the Levencorroch Burn at the small waterfall called Easa Cumhang.[1] The sill is intersected by a 2-foot basalt dyke. It can be traced eastward to the path on the south side of Auchenhew Hill, but apparently does not reach the burn to the east.

A sill on a somewhat lower horizon is exposed in a fine section at the waterfall of Eas Mòr in the Allt Mòr burn running on the eastern side of Auchenhew Hill. The gorge below Eas Mòr heads in an amphitheatral feature caused by the outcrop of a craignuritic felsite sill, 20 to 30 feet thick, forming the waterfall. The sill rests on nearly horizontal Triassic marls, and on the eastern side of the gorge shows a sedimentary intercalation. Beneath the fall the strata are bent and broken by one or two small faults. Another sill of the same material appears at a small fall one-third of a mile higher up the burn, which is here called the Loch Burn.

The cliff at the back of the 10-ft. raised beach below Kildonan Castle is composed of a sill of craignuritic felsite 15 to 20 feet thick. This is well exposed in the quarry at Lloyd's Signal Station, and there rests on sediments which are seen on the seaward side of the quarry. The rock is a typical 'grey basalt' generally with scattered slender porphyritic felspars (6358–9). The central part of the sill is flow-vesiculated, and the elongated cavities are filled with 'green earth' minerals and calcite (25057). The rock weathers with a thick greyish crust, but is blue-grey when fresh. The marginal parts of the sill are slightly more basic than the central part, and Dr. Harker therefore regarded it as a composite sill.[1]

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[1] A sketch of this occurrence is given in J. W. Gregory and G. W. Tyrrell, ‘Excursion to Arran,’ *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, p. 418, but the Auchenhew mass is wrongly called crinanite.

To the west the sill extends much farther than is shown on the One-inch Geological Map (1910). An exposure is seen in the cliff behind the Schoolhouse at Kildonan, half a mile west of Kildonan Castle. To the east the sill extends along the raised-beach cliff up to the houses at Port a' Leacach, where it suddenly ends off. At this point, however, another sill appears on the foreshore, of exactly the same petrographical character. Its upper surface, with patches of sediments still adhering to it, forms a flat spread on the foreshore for about a quarter of a mile to the north-east of Port a' Leacach. This sill appears to have suffered monoclinal bending at places, and patches and sheets of sediments are included within it. Its relation to the Kildonan Castle intrusion is doubtful. It may be the same mass dropped down to the east along a north-west fault, or it may form a separate sill injected on a slightly lower horizon.

One or two intrusions of quartz-dolerite (6413) occur in the fields between Kildonan Castle and the road, below the horizon of the Dippin crinanite.

The island of Pladda, one mile south of Kildonan, is mainly occupied by a well-marked sill which, judging from the Survey specimen (6397), is a quartz-dolerite belonging to the suite under description.

6. *Region West of the Sliddery Valley*

A quarter of a mile north-east of the ninth milestone on the Ross Road, and 3 miles W.S.W. of Lamlash, a small quarry gives a section in a thin sill which shows an extraordinarily intimate interpenetration of a dark compact basalt by spherulitic felsite (Fig. 20). The basalt occurs in angular or sub-rounded fragments enveloped by a matrix of felsite, and the two rocks appear in approximately equal quantity. The same sill is found intersecting the Carboniferous volcanic rocks in the head of the Sliddery Water, about half a mile south-west of the above-mentioned quarry. The section is poor, and the felsite-basalt sill is cut by a thin N.N.W. basalt dyke.

The moor to the north and west of the quarry is strewn with rounded blocks of medium to coarse-grained quartz-dolerite, and there are numerous outcrops of the same rock farther to the west along the Ross Road. This is presumably the elongated sill which is shown on the One-inch Geological Map as extending for about 3 miles on the eastern side of the Sliddery Water.

Nothing is known of the field-relations of the Glenscorrodale mass on the western side of the Sliddery Water. It is represented by two specimens (6401–2) in the Survey collection, from which the sill appears to be a dolerite modified by the incorporation of acid material. The intrusion of Tormusk, to the north-west of Glenscorrodale, is also little known. From the Survey specimen (6407) it appears to be a spherulitic felsite of the suite under description.

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[1] 'Geology of North Arran, etc.', *Mem. Geol. Surv.*, 1903, p. 115.

The complicated ring-shaped outcrop 2½ miles east of Blackwaterfoot, which includes Cnoc Ballygown (735 feet O.D.), Beinn Tarsuinn (965 feet O.D.), and Cnoc an Loch (1107 feet O.D.), belongs to a composite sill including coarse quartz-dolerite (6375, Cnoc an Loch; 6389, Cnoc Ballygown), and various rocks of craignuritic composition (6377, 6390, Cnoc Ballygown). On the One-inch Geological Map it is mapped as dolerite and felsite.

The head of the Allt Cul na h'Eilde provides a section in the northern part of the Beinn Tarsuinn mass. The sill rests on practically horizontal Triassic marls and sandstones. Its base consists of spherulitic felsite, which passes into rocks of craignuritic composition higher up the burn. The summit of Cnoc Ballygown consists of a coarse quartz-dolerite of Garbad type, poorly exposed and much decomposed. Lower down on the western slope the rock becomes distinctly more acid.

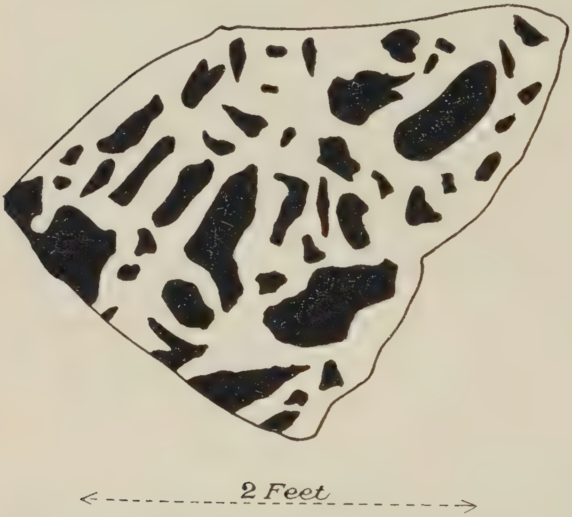

FIG. 20.—*Rock slab showing enclosure of basalt fragments (black) in a matrix of felsite (unshaded). Quarry near summit of Ross road, 3 miles west-south-west of Lamlash.*

It is probable that many of the felsites of the Sliddery district, as, for example, at Bennecarrigan, Glenrie, and in the Clauchan Glen, are related to the quartz-dolerite–craignuritic-felsite suite under description.

In a quarry at Pien Bridge, Shiskine, there is a section in a thin composite sill, the exterior member of which is quartz-basalt, and the interior member a felsite.

C. PETROGRAPHY

The rocks to be described in this section are derived from an oversaturated magma, and in nearly all their varied manifestations show traces of the presence of free silica. Their range of composition varies from basic to acid ; their textures from glassy to coarsely holocrystalline. For descriptive purposes we propose to divide them into three groups according to composition, as basic, intermediate, and acid. The basic types are fine-grained quartz-gabbros or quartz-dolerites ; the intermediate rocks are augite-diorites and rocks of craignuritic composition ; the acid rocks are felsites of distinctive characters belonging to the acid end of the craignurite series.

The nomenclature of these rocks presents a perplexing problem. An attempt has been made in the following descriptions to apply the nomenclature of the similar rocks of Mull.[1] The chief difficulty has been found in regard to the intermediate types which have been termed craignurite in Mull.

Craignurites are rocks in which the matrix has a characteristically immature type of crystallization, with skeletal crystals of felspars and pyroxenes in an acid crypto- or micro-crystalline base. The larger felspar and pyroxene crystals, too, possess an elongate habit.[2] Hence the main features of *craignurite,* as defined in the *Mull Memoir,* appear to be the immature type of crystallization, and the general columnar, acicular, and skeletal development of the minerals.

The compositional range covered by the term craignurite is very wide. It embraces rocks with silica percentages between 55 and 70, the normal and characteristic type, however, containing about 65 per cent. The group, as a whole, should perhaps be referred to as the *craignurite series* ; the normal intermediate type as *craignurite* in the narrow sense ; the basic end-member as *craignurite-dolerite* ; and the acid end-member as *craignurite-felsite.* In Arran, however, rocks which are undoubtedly of craignuritic composition rarely show the characteristic texture and mode of crystallization of the craignurite series. The matrix and mesostasis of many of the rocks certainly show an immature type of crystallization, but it is more of a felsitic and spherulitic character than acicular and skeletal.[3] Many of the Arran rocks closely resemble the rocks of the Cnoc Carnach group of composite sills in Skye.[4]

The basic members of the suite, represented by the analysed rock (24459), seem to be identical with the quartz-dolerites of Talaidh type in Mull.[5] In the field they are dark, fine-grained, minutely-crystalline rocks usually devoid of porphyritic constituents. The type rock comes from the Garbad sill, where it is exposed in the gorge of the Allt Dhepin, near Cnoc an Fheidh. It consists of well-shaped felspar laths, and colourless augite crystals usually well-developed in the prismatic zone, along with iron-ores and a completely-altered second pyroxene, in an abundant, brown, turbid mesostasis containing irregular blebs of quartz and needles of apatite. The felspars are highly zonal, ranging from acid labradorite to oligoclase. Where they are in contact with the acid mesostasis (as in the vein described later) they are surrounded by a thick investment of turbid alkali-felspar, and show signs of corrosion and reaction. The principal pyroxene is a colourless augite, generally with salite striation and enclosing crystals of magnetite. Occasionally it shows a marginal alteration to a yellow-green amphibole ; but more often it is invested by pseudomorphs in a dark-green, fibrous, pleochroic mineral after a second pyroxene, the alteration of which has disengaged much cloudy iron-ore. This pyroxene forms long columnar crystals, and is never fresh. The alteration product has a fibrous structure parallel to the length of the crystals, and cleaves so perfectly that the laminæ are often separated and the interspaces filled with secondary matter. This pyroxene may be the uniaxial enstatite-augite described from Mull rocks of the same suite, or it may be an orthorhombic variety.

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[1] *Mull Memoir,* 1924.

[2] *Ibid.,* p. 227.

[3] Some of the slices were submitted to Dr. H. H. Thomas and Mr. E. B. Bailey, both of whom are of the opinion that the term craignurite should be applied very sparingly to the Arran rocks, as the characteristic texture is quite rare.

[4] A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.,* 1904, p. 215.

[5] *Mull Memoir,* 1924, p. 301 *et seq.*

The mesostasis is a brownish, turbid, felspathic substance with undulose extinction, in which an occasional irregular area of quartz is set, and which is riddled by needles of apatite. In isolated areas it becomes distinctly spherulitic. Its distribution is rather patchy ; and the slice (24459) shows a large irregular area or vein, several millimetres broad, in which the mesostasis has collected. In this area its texture is felsitic or microcrystalline. It contains spongy masses of chloritic material, small well-shaped crystals of magnetite, and the scattered felspars above mentioned which are invested by alkali-felspar.

A specimen from the Glenashdale sill, from below Torr an Loisgte (24867), differs only in inessential particulars from the above. There is little or none of the altered, presumably orthorhombic, pyroxene, and the mesostasis is beautifully spherulitic.

One of the rocks from Auchenhew Hill (6887) is almost identical with that of the Glenashdale sill ; but where the mesostasis is particularly abundant it carries long rods of pyroxene, which show parallel intergrowths of the two kinds above described. A five-fold parallelism of a central and two marginal rods of altered enstatite-augite, with two rods of fresh, colourless, monoclinic pyroxene is occasionally seen. Apatite needles and quartz are relatively abundant in this rock.

Another Auchenhew rock (6886) is decidedly more basic than the above. The amount of interstitial quartz and mesostasis, relatively to the pyroxene, plagioclase, and iron-ores, is much less. The rock of the Pladda sill (6397) is generally similar, but is of finer grain, and shows a tendency towards intergranular texture. From Cnoc Ballygown we have an example of a coarse, almost gabbroidal, type (6389). The pyroxene here seems to be of the fresh monoclinic variety only, and shows an incipient alteration to yellow-green chlorite. The specimen from east of the Boguille track, west-south-west of Tormusk (6375) is a much altered rock of the same character. Another rock from Cnoc Ballygown (6377) is almost a replica of the type rock, except that the pyroxene has gone over entirely to green serpentinous material.

Types of intermediate or craignuritic composition are represented in a coarse-grained form, of which a good example is found in the Tighvein complex, near the shepherd's cairn on the north-east side of Urie Loch (25055). This rock presents a close resemblance to the augite-diorite of the Gaodhail mass in Mull.[1] In hand-specimens it is a light-grey, aphyric rock of medium grain. Under the microscope it shows numerous, euhedral, rectangular, and columnar crystals of zonal plagioclase, with chloritized pyroxene and magnetite, embedded in an abundant mesostasis of turbid alkali-felspar and quartz, which often combine to form a very fine micrographic intergrowth. The felspar is often only singly-twinned and varies from andesine to oligoclase on the margins of the crystals. Where the crystals project into the mesostasis they form the centres of thick investments of micropegmatite, the fibres of which run at right-angles to their margins. Definite crystals of alkali-felspar sometimes occur in the mesostasis, but are invariably intergrown with quartz, and are occasionally moulded by large areas of clear quartz.

A rock from Auchenhew Hill (6885) differs from the above only in its somewhat finer grain, in its abundance of small granules of iron-ores, and the occasional occurrence of a plagioclase phenocryst.

A rock of much the same character, but much finer in grain, and more felspathic than that of Urie Loch, forms the thick veins and patches of light rock which intersect the augite-diorite at the summit of Tighvein (6409). The pyroxene in this rock is fresh, granular, and subhedral, and is a faintly-coloured greenish augite. The specimen from a crag east of Cnoc Dubh, north-west of Tighvein (6410), is of similar character, but is highly weathered. The light-coloured component of the Cnoc Ballygown mass (6390) also belongs here. The matrix, however, is very turbid, and is somewhat richer in quartz than usual. The light-coloured matrix of the xenolithic rock which forms the summit of Sguiler (25054) belongs to the same general type (p. 135).

Rocks of intermediate composition, but definitely craignuritic in texture, are rare in Arran, and are very poorly represented in the Survey collection. A rock from near the base of the Glenashdale sill, at the top of the great waterfall in Glen Ashdale, appears to be a craignurite near the basic end of the series (6382). It consists of numerous small felspar laths, much altered and albitized, in an obscure groundmass composed of felspar microlites, chlorite, iron-ore, turbid matter (alkali-felspar ?), and irregular areas of quartz.

Many of the rocks belong to the acid end of the craignurite series. These types are distinguished in the field by their characteristic compact texture, light bluish-grey colour, and by the presence of small, sporadic phenocrysts of white felspar, which are sometimes aggregated into little stellate groups (25057, 25059). These rocks tend to have an irregular slabby fracture, and are often characterized, especially near sill contacts, by flow-elongated vesicles, which may be partly or wholly filled with calcite and 'green earths.'

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[1] *Mull Memoir*, 1924, p. 218.

A rock of these characters which has been analysed (Table II., V.) is that of the Allt Dhepin sill, taken at the waterfall near 786 feet O.D. in the Allt Dhepin (24458). Under the microscope it shows a few microphenocrysts of alkali-felspar (? soda-orthoclase) set in a groundmass consisting of well-shaped felspar microlites, mostly alkali-felspar but with a few of oligoclase, and a very abundant, turbid, felspathic base with irregular areas and blebs of quartz. This base sometimes shows an obscure intergrowth with quartz. Ferro-magnesian elements are represented by a few small specks of chloritic matter and iron-ores. The norm of this rock gives 38 per cent. of quartz. but as the visible quartz does not nearly amount to this figure, the bulk of the free silica must be occult in the turbid base.

Of almost identical characters is the acid rock which forms the basal member of the Glenashdale sill (6383), and the main rock of the Kildonan Castle sill (6359), which was identified by Dr. Harker as trachyte.[1] A recently-collected specimen (25057) is slightly coarser in grain, and many of the felspar laths are certainly oligoclase and not alkali-felspar. In these Kildonan rocks there is a tendency for elongation in both felspars and chloritized pyroxenes, and the felspars are often forked and skeletal. Hence there is an approach to the characteristic craignurite texture. At the base of the Kildonan sill a somewhat more basic facies occurs, which has been described by Dr. Harker [2] in the following terms :—

'A specimen from the lower part [of the sill] is a grey, fine-textured rock, without evident porphyritic crystals, and gives the specific gravity 2·68. In a thin slice [6358] it is found that the felspars, in little "lath-shaped" sections about $\frac{1}{100}$ inch or less in length, constantly give quite low extinction-angles. Many of the crystals are striated, and the dominant felspar must be near oligoclase in composition, though orthoclase may perhaps be present in addition. The augite preserves its ophitic habit, but is in great part destroyed. In addition there are abundant little crystal-grains of magnetite, and in places a little interstitial quartz. The rock presents the characters of a partially acidified dolerite, the low density being very significant in this respect.'

The rock of the massive dyke at the north end of the Largybeg Point section (Fig. 7) is an acid member of the craignurite series, and possesses a highly characteristic craignuritic texture (25056).

The rock of the small quarry in the Lag a' Bheith (p. 137) is somewhat richer in chloritized pyroxene and iron-ores than the type rock of the Allt Dhepin sill (25059). Another specimen (25076) carries large glomeroporphyritic segregations of altered plagioclase felspar, chloritized pyroxene, and skeletal ilmenite, which collectively make up a rock resembling the above-described augite-diorite.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol Surv.*, 1903, p. 115.

[2] *Ibid.*, p. 115.

A cryptocrystalline, spherulitic type (25060), and a flow-banded, spherulitic, glassy facies (25061), come from a 5-foot sill in the main western headwater of Strathwhillan Burn, near Brodick. The black glassy material from Glen Cloy, Brodick, described by Dr. A. Scott,[1] is a pitchstone-like rock of similar characters (24391). The rock which underlies it is a felsite with a typical craignuritic texture (24390).

Allied to the craignuritic felsites are certain other acid intrusions in the southern half of Arran, as, for example, the spherulitic felsite or granophyre which is inserted at intervals between the Baoileig and Garbad sills in the Glen Ashdale region ; other large acid sills, as, for example, those of the Sliddery valley ; and the microgranite which is involved in the Tighvein complex. The spherulitic felsite of Glen Ashdale is represented by a specimen from below Cnoc Mòr on the north side of the glen (24873). This is a light ash-grey rock, rather porous and drusy, with a few small microphenocrysts of felspar. In thin section it shows a large number of curious rounded masses of fine micropegmatite, which are often involved with crystals of quartz and felspar. These masses are apparently reconstituted spherulites. They are set in a dense felsitic groundmass of the usual type. The phenocrystic felspar is largely oligoclase or oligoclase-albite. The original pyroxene (?) has given rise to some disseminated chlorite and epidote. Some of the quartz grains have rounded or embayed shapes which are probably due to a resorption effect. The felsitic granophyre of Torr Beag, from the quarry north of Glenrie, Sliddery valley (6400), shows very similar features, but is richer in the micrographic spherulites, and is devoid of felspar microphenocrysts. The spherulitic rock from Tormusk (6407) is a member of this group.

The large acid intrusion which forms part of the Tighvein complex is treated here, as it is almost certainly closely associated with the augite-diorites of that centre. It may be regarded as the most fully crystallized representative of the partial magma which gave rise to the acid craignurites and craignurite-felsites. It is represented by three slices in the Survey collection (6384, 6411, 24877). The specimen from a twelfth of a mile north-east of the summit of Tighvein (24877) is a light greyish-yellow rock of minutely-granular aspect, with sporadic rectangular microphenocrysts of felspar. In thin section the three slices mentioned above show a remarkably uniform type of microgranite consisting mainly of anhedral quartz and turbid felspar, with an allotriomorphic or aplitic texture. There is a tendency to imperfect granophyric relations between the two minerals. The felspar is difficult to determine, but appears to be mainly an untwinned alkali-felspar (soda-orthoclase ?). Some lath-shaped sections show simple twinning. The microporphyritic felspars are mainly soda-orthoclase, but a few are albites or oligoclase-albites, with an investment of soda-orthoclase. All the felspars are much weathered. The only mafic constituents are a few specks of iron-ore and shreds of yellow serpentinous material.

Xenolithic and Hybrid Rocks.—In the *Mull Memoir* [2] it is shown that the late acid residues of the intermediate and subacid magmas have reacted with earlier minerals, and that these effects are particularly marked when the residual liquor has migrated within the limits of the individual intrusion. Many of the mineralogical phenomena thus produced are entirely similar to those which are due to hybridization, *i.e.* to the commingling of magmas, or to the assimilation of foreign material within a magma. Since the validity of the reaction principle seems to be unquestionable,[1] it is clear that assimilation and hybridization effects should only be inferred when there is good evidence of magmatic mingling or the dissolution of xenoliths. Some of the rocks described above have been regarded as acidified basalts and dolerites, or basified felsites and granophyres, but there is no reason to doubt but that many of them are perfectly normal products of differentiation, assuming that reaction between the early-crystallized minerals and the late acid residua has been in progress.

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[1] *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, p. 142.

[2] p. 355.

Nevertheless there are many undoubted examples of partial assimilation and hybridization in Arran, in which fragments, generally of basic composition, are enveloped in acid magmas, with reactional or solutional effects. The Sheans and the intrusion at the summit of Sguiler furnish the best examples in the Survey collection of xenolithic rocks within the group described in this chapter ; but there are other fine examples between the gabbro and granophyre of the Central Ring Complex (p. 177). The rocks of the Sheans are represented by two slices (24384–5). In (24385) the dark compact xenoliths are seen in thin section to consist of a fresh quartz-basalt with a fine intergranular texture, little granules of augite and magnetite being inserted, often in single rows like strings of beads, between diversely-orientated felspar laths. The composition of the felspar ranges between andesine and oligoclase ; the ends of the felspar laths are sometimes embedded in small areas of chlorite which seem to have replaced a pyroxene. A small amount of quartz occurs interstitially.

The light acid rock in which the xenoliths are enveloped differs from the xenoliths in its somewhat coarser grain, the greater relative abundance of felspar, and in the presence of alkali-felspar which forms a scanty mesostasis along with quartz, and which also forms a few phenocrysts mainly of perthitic soda-orthoclase. The boundary between xenoliths and matrix is quite sharp, and there has been little or no reaction between the two. Little fragments of the xenoliths have, however, been spalled off, and can be found in process of disintegration. The slice (24384) is quite similar except that it is much weathered, as the specimen from which it was cut was collected to show the mode of weathering of the xenolithic rock. The xenoliths in this rock show a few phenocrysts of acid labradorite.

The rock of Cnoc Dubh (25048), of which the Sheans are probably outliers, is similar to the more basic xenoliths of the Sheans. It is a porphyritic quartz-basalt or dolerite with intergranular texture. The phenocrysts range up to 5 mm. in width, and consist of acid labradorite. Some of them are albitized, and others show a narrow rim of alkali-felspar, which appears to be continuous with a scanty mesostasis. In the xenolithic rock of Sguiler (25054) the xenoliths consist of a dense quartz-basalt of character generally similar to that of the Sheans, enveloped in a matrix resembling the more acid type of augite-diorite which is prevalent in the Tighvein complex. There has been some reaction in this case, as skeletal iron-ore has been thickly developed in the xenoliths near the contacts, and specks of iron-ore and shreds of chloritic matter are decidedly more abundant in the acid rock nearer the contacts with xenoliths than in parts remote from them.

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[1] N. L. Bowen, 'The Reaction Relation in Petrogenesis,' *Journ. Geol.*, vol. xxx., 1922, pp. 177–198.

A slice from the sill in the Rosa Water, Brodick (7538) shows small, rounded xenoliths of quartz-basalt in a craignuritic matrix. Two slices of rocks from an intrusion 500 yards W.N.W. of Glenscorrodale House, Sliddery valley (6401–2), show large xenocrysts of alkali-felspar and quartz in a matrix of craignuritic composition. The quartz has been much corroded, and shows beautiful reaction rims consisting mainly of pyroxene granules.

D. CHEMICAL COMPOSITION

Analyses of quartz-dolerite or basic craignurite of the Garbad sill, and of craignuritic felsite from the Allt Dhepin sill, both taken from the type section of the Allt Dhepin (p. 126) have been made for this Memoir by Mr. E. G. Radley (Table II.—4 and 5). Thus typical specimens of rocks which represent the end-members of the craignurite series have been selected for analysis.

TABLE II

	4	E	F	5	6	G	H
SiO_2	54·00	52·16	55·82	71·58	69·26	70·70	71·30
Al_2O_3 ..	13·09	11·95	11·47	12·20	11·60	11·78	11·24
Fe_2O_3 ..	3·53	4·86	3·68	1·51	1·31	1·32	1·80
FeO	8·45	9·92	7·66	1·77	2·57	3·45	2·84
MgO	3·49	3·77	4·08	·50	1·10	·53	·61
CaO	5·55	7·14	7·88	1·98	2·61	1·30	1·56
Na_2O ..	3·27	2·36	2·53	2·83	2·08	2·48	3·44
K_2O	1·80	1·74	2·00	3·86	3·88	4·71	4·66
$H_2O > 105°$ ..	1·71	1·95	1·88	·76	1·67	1·14	1·04
$H_2O < 105°$ ..	1·26	·56	·66	1·10	1·61	·50	·39
TiO_2	2·83	3·25	1·62	·44	·45	1·27	·58
P_2O_5	·31	·24	·23	·13	·10	·26	·22
MnO	·37	·18	·40	·31	·45	·07	·31
CO_2	·25	·18	·08	1·07	1·76	·51	—
S	—	·18	—	—	—	·08	—
FeS_2	·14	—	·09	nt. fd.	nt. fd.	—	nt. fd.
(Ni, Co)O ..	nt. fd.	—	·04	nt. fd.	nt. fd.	—	nt. fd.
BaO	·02	—	·03	nt. fd.	nt. fd.	—	·07
Li_2O	tr.	—	tr.	tr.	nt. fd.	—	? tr.
	100·07	100·44	100·18	100·04	100·45	100·10	100·06

4. (24459). Lab. No. 828). Quartz-dolerite from the Garbad sill (p. 126) gorge in Allt Dhepin, one-third of a mile E.N.E. of 873 feet O.D., Cnoc an Fheidh, Whiting Bay, Arran. *Anal.* E. G. Radley.

E. (18467. Lab. No. 444). Quartz-dolerite (Talaidh type), cone sheet, 70 yards south of summit, Cruachan Dearg, Mull. *Anal.* F. R. Ennos. Quoted from the *Mull Memoir*, 1924, p. 17.

F. (16800. Lab. No. 412). Craignurite (basic), cone sheet, Allt an Dubh Choire, 1220 yards above junction with Scallastle River, Mull. *Anal.* E. G. Radley. Quoted from the *Mull Memoir*, 1924, p. 19.

5. (24458. Lab. No. 827). Felsitic end-member of the craignurite series, from the Allt Dhepin sill (p. 126), at waterfall in the Allt Dhepin near 786 feet O.D., half a mile S.S.W. of Loch na Leirg, Whiting Bay, Arran. *Anal.* E. G. Radley.

6. (24453. Lab. No. 823). Felsite (devitrified pitchstone ?, *see* p. 211), probably of the craignurite series, 24-foot dyke in Glen Dubh Water, 100 yards above confluence with Glen Ormidale Water, 825 yards W. 37° S. of Kilmichael, Brodick, Arran. *Anal.* E. G. Radley.

G. (18464. Lab. No. 443). Felsite allied to inninmorite, sill, south of Coire Buidhe, between the 800-foot and 900-foot contours, about half a mile north of Carsaig, Mull. *Anal.* F. R. Ennos. Quoted from the *Mull Memoir*, 1924, p. 20.

H. (16803. Lab. No. 394). Granophyre allied to craignurite, cone sheet, Craignure Bay, shore 50 yards N.N.W. of U.F.C. Manse. *Anal.* E. G. Radley. Quoted from the *Mull Memoir*, 1924, p. 20.

The closest Mull analogues of the Arran quartz-dolerites are the quartz-dolerite of Talaidh type from Cruachan Dearg (18467), and the basic craignurite of a cone sheet in the Allt an Dubh Choire (16800), the analyses of which are tabulated for comparison in columns E and F of Table II. Calculation of the norms shows that both the Mull rocks are decidedly more femic than that of Arran, the percentages of salic minerals being 58·4 and 59·2 respectively, as against 64·2 for the Arran example; and they are richer in plagioclase felspar, and poorer in alkali-felspar than the Arran type, as is shown by their higher lime, and lower alkalies and alumina.

The rock from the Allt Dhepin sill, which was selected as typical of the acid end-members of the craignurite series, turns out to be a thoroughly acid type with 38 per cent. quartz as computed from the norm of the analysis (5, Table II.), and 89·2 per cent. of salic constituents. Along with it are tabulated the analysis of a felsitic dyke rock from Glen Dubh, Brodick (6, Table II.), which is dealt with in more detail later (p. 235), and the analyses of two Mull rocks, a 'felsite allied to inninmorite' from Carsaig (G, Table II.), and a 'granophyre allied to craignurite' from Craignure Bay (H, Table II.). Inspection of these four analyses shows their close general similarities. The only notable difference is that the Mull types are somewhat richer in alkalies, and especially in potash, than the Arran rocks. The comparison given below exhibits their variations in the amount of salic constituents and in quartz :—

	% Salic Constituents.	% Quartz.
Anal. 5 ..	89·2	38·0
Anal. 6 ..	83·6	38·5
Anal. G. ..	87·7	35·2
Anal. H. ..	85·8	27·8

G.W.T.

CHAPTER XIII

THE KAINOZOIC IGNEOUS ROCKS—(*continued*)

THE NORTHERN GRANITE

GENERAL FEATURES

THE great boss of granite which is the nucleus of the northern portion of the island, has been a subject of interest to geologists since the time of Hutton towards the close of the eighteenth century. Its form is nearly circular, being 8 miles by 7, and its circumference, viewed on the large scale, is very even and regular, with no large projections or detached bosses,[1] and generally its boundary is sharply defined. There are two varieties of the granite; one, of coarse grain and earlier in age, forms the exterior of the mass, while a fine-grained and newer variety occupies the interior. The coarser kind is composed mainly of quartz and orthoclase felspar, with abundance of black or brown mica in certain places, but generally the mica is not conspicuous. Some plagioclase felspar also occurs in the granite. Here and there in the granite, dykes, sheets, and patches of a finer-grained rock occur, and these are not always later intrusions, but rather of the nature of segregations, for they may be seen sometimes to merge insensibly into the general mass. Patches of this kind are not uncommon near the junction of the granite with the surrounding rocks.

Many joints traverse the granite, and these in places are horizontal, or they dip at a comparatively gentle angle, so that the rock has a remarkably bedded appearance. The most marked joints in other localities are vertical, or dip at steep angles into the glens, their inclination not seldom coinciding with the slope of the ground, and forming surfaces which are very difficult to traverse. Occasionally we find more than one set of joints developed in the same rock, *e.g.* both horizontal and vertical joints, but the latter are generally most conspicuous near and parallel to the numerous intrusive dykes.

Some of the finest intrusive junctions of the granite with the older schists in North Glen Sannox were described by Hutton [2] more than a century ago, and these and other junctions at Tor Nead an Eoin, and elsewhere on the eastern side of the mass, have since been often referred to, but others quite as striking occur on the east side of Glen Catacol at Madadh Lounie, and in several places north of Meall nan Damh. The granite maintains generally its ordinary coarse character near its junction with the schists, but there are several places where it is fine grained at the margin.

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[1] There is, however, a marked bulge to the west of Corrie, showing a departure from the true circular outline of about a mile in a radial direction (*see* One-inch Geological Map, 1910, and Plate III). The long, straight, north-eastern boundary between Corrie and Glen Chalmadale is a fault (*see* p. 162), and may be connected with the above-mentioned bulge in some way.
G.W.T.

[2] *See his* 'Theory of the Earth,' vol. iii., p. 220.

A good junction between granite and schist is seen near the 800-foot contour in the Allt a' Chapuill, west of Sannox. The contacts are sharp but very sinuous in outline. The general line of contact, however, when mapped, shows a lobe of granite projecting downstream. At the junction the granite becomes fine grained and porphyritic, and the schists are hornfelsed with the obliteration of their schistose structure. A marked line of crush intersects the granite near 1073 feet O.D., parallel to a system of vertical joints running in a direction a few degrees west of north. Another joint-system crosses the above at right-angles, and gives rise to straight-sided little gorges in the burn, whereas the former system causes waterfalls.

In Coire na Ciche, at the head of the Allt a' Chapuill, the main structural planes dip south-west, inwards towards the centre of the granite mass. On Cioch na h-Oighe, however, the bare rock surfaces show the usual outwardly-dipping slabs, which are probably exfoliation effects (*see* p. 160).

In the White Water, south-west of Corrie, the junction between granite and the Old Red Sandstone is a fault (*see* p. 162). The granite is well sheeted near the contact, and the sheets dip outwards in conformity with the dip of the adjacent sediments. There are many veins and irregular patches of aplite, which also forms bands dipping with the above-mentioned sheeting. At one place there is a thin vein ($\frac{1}{4}$-inch) of a black compact substance (? pseudo-tachylyte), which on being followed, becomes at first thicker, and then frays out into threads. At the foot of the cascade the granite is dark and biotite-bearing, but the mass of the rock is coarse, miarolitic, and poor in dark minerals.

Along the Stacach *arête* north of Goatfell, especially near 2659 feet O.D., the granite becomes very coarse, and in places miarolitic. It is cut by thick, irregular masses of fine-grained granite, and by numerous aplite dykes and veins. The latter can also be well studied on the main path from Brodick to the summit of Goatfell. The principal dip of the granite slabs on Goatfell and the Stacach ridge (Plate III) is to the east at angles varying from nothing to 20°. On the ridge connecting Stacach with The Saddle, separating Glen Rosa from Glen Sannox, there are numerous thick masses and dykes of aplite penetrating coarse granite.

In the Garbh Allt, a western tributary of Glen Rosa, the contact between granite and schist can be seen at about the 700-foot contour, half a mile W.S.W. of the Garbh Allt bridge in Glen Rosa. The granite becomes of appreciably finer grain only within a foot or two of the contact. In Glen Rosa itself the schist-granite contact can be located to within a yard in the bed of the river, a few yards below its confluence with the Garbh Allt. The granite closest to the junction appears to be somewhat more basic than the normal type, is intersected by fine granophyre veins, and shows large miarolitic cavities in which good crystals of smoky and amethystine quartz can be found. G.W.T.

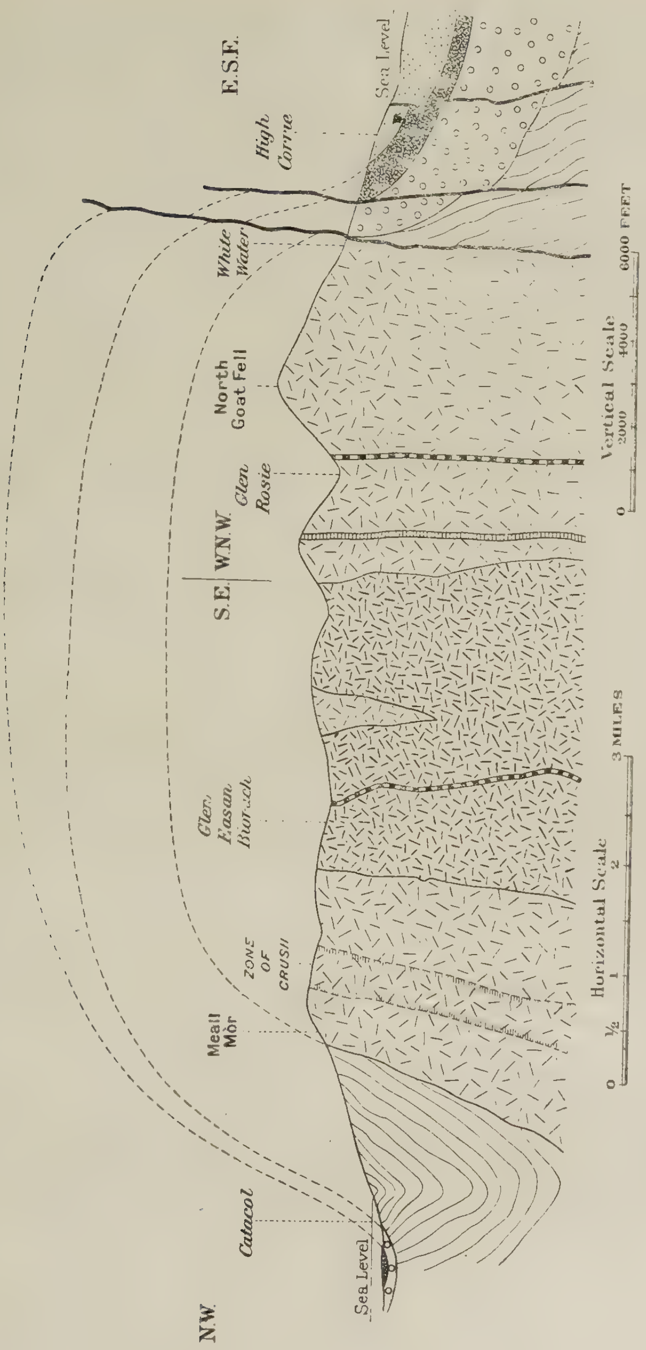

FIG. 21.—*Section across North Arran Granite. For explanation of ornaments see Plate III.*

Fine-grained Granite.—Several writers have described the finer-grained granite in the interior without, however, defining its exact boundaries. It is intrusive in the coarser variety which surrounds it, and is evidently of somewhat later date, but both belong to the same geological period and are probably parts of the same igneous magma, for they have generally the same sets of joints, and are alike pierced by similar dykes of pitchstone, felsite, quartz-porphyry, and basalt. The finer variety occupies nearly all the west side of Glen Iorsa, so that on this side of the island the coarser kind of granite is but a comparatively narrow strip varying from one mile in width to not more than a furlong at Iorsa Loch. On the east side of the Iorsa most of the granite is of the coarser variety, and the boundary between it and the fine is tortuous, some bays of the fine being almost detached and surrounded by the coarse. The fine granite occupies about 14 square miles, which is one-third of the whole granitic area.

All the peaky hills are formed of the coarse kind, the fine variety forming rounded or flat-topped hills, generally of lower elevation. Usually the fine variety breaks up into small slabs, which often so entirely cover the surface of the ground that no solid rock is observable. The debris of this rock is nearly white in colour, while the decomposition of the coarse granite produces a coarse, brown sand. Occasionally, however, the finer granite becomes coarse grained and massive ; it then breaks up into larger blocks and forms crags. Good junctions of the two rocks are to be seen on the south side of Beinn Bharrain, on Sail Chalmadale, and in Glen Easan Biorach. South of Beinn Bharrain the junction of the two rocks is generally a vertical line which passes across the jointing, and both kinds of granite may be observed in one and the same slab. In Glen Easan Biorach also, the finest junction at the foot of the stream running north from Creag Dhubh is vertical ; but often in this glen the boundary line is not well defined for some yards, owing to admixture of the two kinds. There seems no evidence anywhere that the fine overlies the coarse granite, and the appearances west of Cir Mhòr relied on for the support of this view are certainly deceptive.

In addition to the main mass of finer granite, numerous small dykes and sheets of it have been intruded into the coarse in various places, but most of these are not large enough to be separately mapped. One of the largest detached masses occurs on the top of Beinn Nuis, between the Ordnance Station and the remarkable rock called Caisteal an Fhionn. It is apparently of an oval outline, and its greatest length from north to south about 300 yards. Another is found near the head of Glen Sannox on the south side of Caisteal Abhail, where the rock has a markedly jointed structure. In this is a closely laminated band of fine granite, about 9 feet in width, which may be traced for 100 yards or more. This is a peculiar rock, and differs from the fine granite which surrounds it in having an approach to a linear arrangement of the quartz in the rock, and it weathers into such thin plates or slabs that at first sight it reminds one rather of a schist than of a granite. Its laminæ, however, dip steeply to the west, exactly in the same way as do the joints in the neighbouring fine granite. In some places it has the appearance of an injected vein.

Drusy cavities containing smoky quartz and orthoclase crystals are common in both granites.

A granitic or granophyric dyke occurs in Glen Chalmadale to the east of Lochranza, and appears to have an N.N.W. course. It crosses the main stream of the glen at a point nearly due north of the hill called the Clachan and 200 yards south-east of the foot of a branch burn called Allt na Meanie which comes in from the north. The rock is light-coloured, of rather fine grain, has many small drusy cavities, and altogether much resembles some varieties of the finer granite of the interior or the granophyre of the southern tract. The dyke is from 25 to 30 feet wide, but only the central portion appears to be granitic ; the edges are finer in grain and of a darker colour, and are probably of intermediate or basic composition. The dyke appears again in Allt na Meanie, but cannot be traced continuously. Rock, however, of the same character appears at the head of a burn a mile distant to the north-west and a little to the south of the most westerly of the old slate-quarries. This is quite three-quarters of a mile distant in a straight line from the edge of the great granite mass.

The granite dykes which are found within the granite area are much finer in grain than even the fine-grained mass of the interior; they are, in fact, of the nature of elvans, and seem essentially composed of felspar and quartz. W.G.

PETROGRAPHY

Dr. A. Harker's account of the petrography of the northern granite mass is as follows :[1]—

'The first microscopical investigation of the Arran granites was made by Prof. Zirkel,[2] whose account of the rocks was published in 1871. Mr. Teall[3] added to this some particulars, and, like Delesse, compared the Arran granites with those of the Mourne Mountains in Ireland, doubtless also of Tertiary age. Several writers have recorded the occurrence of special minerals in the druses of the granites.

'Although the *northern area of granite* has been separated into coarser and finer varieties, the rocks do not differ in any important particular, excepting texture. They are biotite-granites, with some tendency to granophyric modifications. A specimen of the coarse type from the top of Goatfell (9469) shows crystals of felspar up to ½-inch long and quartz-grains and mica-flakes up to ¼-inch. The rock of the central part of the area is of considerably finer texture ; and the same is true of apophyses, in which also there is sometimes a porphyritic tendency, indicated by the occurrence of a few relatively large crystals of felspar (9476). It can be seen in the hand-specimens that the quartz tends to form grains, which are sometimes enclosed in the felspar ; also that the biotite, which occurs only sparingly, is often in very irregular shapes, having crystallized after part of the felspar. Another feature, very conspicuous in most of the rocks, is the occurrence of numerous little drusy cavities of irregular form, on the walls of which the quartz and felspar assume good crystal-faces.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, pp. 104–105.

[2] *Zeits. deuts. geol. Ges.*, vol. xxiii., 1871, pp. 6–9.

[3] 'British Petrography,' 1888, p. 328. See also *Ann. Rep. Geol. Surv.* for 1896, pp. 75, 76.

'Thin slices reveal no other mineral, except an occasional grain of magnetite and some minute crystals of zircon enclosed in the biotite. The felspar is partly striated oligoclase, but chiefly what more resembles orthoclase. Much of the latter, however, has a fibrous appearance, becoming more evident with incipient alteration, and probably indicating a microperthitic intergrowth. The quartz contains many minute fluid-pores with bubbles, and in some of these cavities Zirkel detected minute cubes of salt. The mineral is generally idiomorphic towards the orthoclase and microperthite, but it also tends to be intergrown in an irregular fashion in those felspars. In the finer-grained type of rock the micrographic intergrowth is sometimes more regular, and one specimen from Glen Catacol, at the foot of Allt nan Calman, is a very beautiful granophyre (9471). It contains much micropegmatite of a very delicate kind, which is often grown round the felspar crystals, and, when it surrounds orthoclase, has its felspathic element in crystalline continuity with the crystal itself.

'The granites of the northern and larger area, coarse and fine together, belong thus to a well-characterised type. The British rocks with which they compare most closely are undoubtedly those of the Mourne Mountains. The other British Tertiary granites—such as those of Skye and Mull—are usually hornblendic or augitic, and they run more frequently than these into granophyric varieties. An interesting point in common between the Arran and the Mourne rocks is the occurrence of special minerals in the druses. Albite, beryl, topaz, and garnet have been recorded in the druses of the Arran granite, besides stilbite (Macculloch).

'A specimen from an isolated area of coarse granite in North Glen Sannox is found to be identical with the rock of the main mass (9475). Some dykes traversing the mica-schists show a very different micro-structure. Two examples have been examined, one from Glen Chalmadale and the other from S.W. of the Cock slate-quarry (9482, 9483). They are fine-textured but still drusy rocks of pale colour. Both are found to be typical spherulitic granophyres. Crystals of quartz and felspar of small dimensions are enclosed in the spherulitic groundmass and have often served as nuclei for the spherulites. The inclusions in the quartz are here of glass, not of liquid.'

In some slices the plagioclase felspar is nearer albite than oligoclase. The analysed rock (24380), from the Rosa Water, half a mile above its confluence with the Garbh Allt, is a coarse-grained variety which corresponds in all particulars with Dr. Harker's description. The aplite dykes and veins are white or light-grey rocks with a typical saccharoidal texture, and are composed of an allotriomorphic mixture of soda-orthoclase and quartz, with a little oligoclase-albite, and a few shreds of biotite. A specimen collected from the eastern face of Cir Mhòr (25074) is comparatively rich in biotite.

The chemical composition of the dominant coarse-grained variety of the northern granite is given in Table III., 7. In heavy residues from specimens collected at the same locality Dr. W. Mackie has found fluorspar ; but fluorine, which was specially tested for by Mr. B. E. Dixon under the direction of Mr. R. Sutcliffe, of the Survey Laboratory, could not be detected in the analysed specimen. The composition of the northern granite is generally similar to that of the granophyric granite of the Allt nan Dris (Table V., 9), and the quartz-porphyry of Bennan Head (Table VI., 11) amongst Arran rocks. Both these rocks, however, are poorer in alkalies, especially potash, than the northern granite ; the Bennan Head quartz-porphyry is also poorer in soda. None of the analysed granites or granophyres of Mull is strictly comparable with the Arran granite ; and the only comparable Skye granite is that of the Beinn an Dubhaich boss, of which the silica percentage is 76·71. Dr. A. Harker includes this granite with those of Arran, St. Kilda, and the Mourne Mountains, as a subgroup of the British Kainozoic granites in which the silica percentage ranges from about 75 to 77, and the ferro-magnesian mineral is characteristically biotite.[1] In the second subgroup, to which some of the acid plutonic rocks of Skye, all those of Mull as yet analysed, and some of the other Kainozoic centres, belong, the silica percentage is from 70 to 72, and the ferro-magnesian minerals are hornblende and augite. This subgroup seems to be practically identical with the acid end-members of the craignurite series.

TABLE III

	7	I	J	K
SiO_2	74·87	76·71	72·78	75·00
Al_2O_3	11·24	—	—	13·24
Fe_2O_3	·34	—	—	2·52
FeO	1·22	—	—	—
MgO	·22	—	—	—
CaO	1·30	·47	—	·69
Na_2O	3·31	—	4·08	3·07
K_2O	5·68	—	5·18	4·33
$H_2O > 105°$	·49	—	—	·80
$H_2O < 105°$	·29	·22	·34	—
TiO_2	·26	—	—	—
P_2O_5	·09	—	—	—
MnO	·05	—	—	—
CO_2	·49	—	—	—
FeS_2	·33	—	—	—
Cr_2O_3	·02	—	—	—
BaO	·04	—	—	—
Li_2O	·00	—	—	—
F	nt. fd.	—	—	—
	100·24	—	—	99·65

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[1] 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 153.

7. (24380. Lab. No. 820). Biotite-granite, northern granite mass, Glen Rosa, half a mile above confluence with Garbh Allt, Arran. *Anal.* B. E. Dixon.
I. (8693). Granite of Beinn an Dubhaich boss, Allt Cadha na Eglais, Skye. *Anal.* W. Pollard. Quoted from A. Harker, 'Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 153.
J. (8856). Riebeckite-granophyre, between Meall Dearg and Druim an Eidhne, Skye. *Anal.* W. Pollard. Quoted from A. Harker, 'Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 153.
K. Biotite-granite, Slieve Corragh, Mourne Mountains, Ireland. *Anal.* S. Haughton, *Quart. Journ. Geol. Soc.*, vol. xii., 1856, p. 192.

A partial analysis of the Beinn an Dubhaich granite, and an old analysis of the Mourne Mountains granite, are tabulated for comparison with the analysis of the Glen Rosa rock. The calculation of the norm of the latter gives quartz, 32·6; orthoclase, 33·9; and albite, 26·2 per cent. There is no anorthite as the available alumina is fully satisfied by potash and soda, leaving an excess of soda which goes to form about 1 per cent. of ægirine. This peculiarity of composition is perhaps significant in view of the tendency for ægirine and riebeckite to occur in some acid members of the Kainozoic igneous suite of the Western Isles. In this connection it may be noted that a partial analysis of the riebeckite-granophyre of Skye (Table III., J) shows figures for silica, soda, and potash, which do not differ widely from those of the Arran rock. G.W.T.

METAMORPHISM AROUND THE NORTHERN GRANITE

The alteration of the surrounding rocks by the intrusion of this great mass of granite is much less than might have been expected. Often the metamorphism seems to amount to little more than mere induration, and the adjoining rock is in some cases not more altered apparently than sandstone is near some of the dykes in the island. The fine-grained schistose rocks assume a bluer colour and break with a splintery fracture, while the Old Red Sandstone loses its purple or chocolate colour and becomes grey and very hard. Yet in most cases the bedding still remains distinct, though in some the bedding or foliation is rendered very obscure and a set of joints produced parallel to those in the granite itself. The alteration is perhaps greatest in Glen Rosa, where it seems to extend 300 yards into the schists from the junction. Between Glen Catacol and Glen Easan Biorach the altered and hardened schist band is 200 yards wide or more, and it forms a marked ridge which is higher than the granite adjacent, and it also gives rise to gorges in the two streams.

Under favourable circumstances certain minerals appear to have been developed in adjacent rocks by the action of the granite, as andalusite in the schists of North Glen Sannox, and epidote in the altered rocks at the White Water junction, and at Allt a' Chapuill near Cioch na h-Oighe. Biotite has also been developed at the White Water by contact alteration. Perhaps the most marked instances of metamorphism are those which are found in certain basic dykes which are of earlier date than the granite intrusion. One of these, penetrated by granite or granophyric veins, is visible in the Cnocan Burn below the old mill-dam.[1] It is an altered dolerite in which the plagioclase felspars and the patches of iron-ore have retained their original characters, while the augite has been converted into aggregates of pale-green hornblende, with which some brown mica is associated (7442). On the opposite side of the mass of granite another example of the same kind of alteration is found in a dyke nearly half a mile north-west of Lochan a' Mhill. This was described by Ramsay ('Geology of the Isle of Arran,' p. 49), who, however, thought that the dyke was intrusive into the granite. One of the most marked examples of alteration by the granite is found in Glen Iorsa, 400 yards W.N.W. of the boathouse, Loch Iorsa. A highly-altered argillaceous schist seems totally reconstituted, and contains abundant andalusite [2] in relatively large irregular crystals, and much finely-divided biotite (9404). This locality is nearly a quarter of a mile from the edge of the granite. In Glen Scaftigill, near the granite, a gritty schist is highly metamorphosed. There is new-formed biotite in large flakes, and there has been a recrystallization of much of the finer-grained portion of the rock, with doubtful andalusite formed in places. W.G.

The (?) Arenig lavas come into contact with the granite on and near Cnocan Donna, at the north-eastern end of the Suidhe Fhearghas ridge, and half-way between North and South Glen Sannox. The rock here is tough and hard, and has its foliation and other structural planes obliterated. It is much shattered, and hard to identify. The slices (9385–6) may have been cut from specimens of these altered rocks (*see* p. 27). Metamorphosed rocks are found to within 50 yards of the granite *in situ*, but the actual contact is not seen as the junction is marked by a line of swamp.

The altered schist at the Allt a' Chapuill contact (p. 150) is represented by the slice (9409). It shows numerous angular fragments of a recrystallized quartz mosaic in a fine-grained quartzo-felspathic matrix, in which new biotite has been developed.

At the White Water junction south-west of Corrie the granite is in contact with Old Red Sandstone, but the junction is undoubtedly a fault.[3] The induration of the Old Red Sandstone does not extend to more than 50 yards from the contact. It is altered to a hard, greenish quartzite, and contains shaly bands altered to a hard, green, flinty material. In general there is little or no new mineral formation save the introduction of epidote and perhaps chlorite ; but a slice (7441) labelled 'altered sandstone, White Water, near granite junction' does show a considerable development of newly-formed biotite in a coarse felspathic grit.

In the Uisge nam Fear, about half a mile south of the White Water junction, a band of schist again intervenes between the granite and the Old Red Sandstone (Fig. 2, p. 54). The latter, however, is distinctly indurated, and consists of dark, glistening quartzite, frequently of a greenish colour through the abundance of epidote. The schist shows foliated and wrinkled surfaces in places, but mostly it is hornfelsed, and hard to distinguish from the indurated Old Red Sandstone. Much of it must originally have been a quartz-schist, but is now metamorphosed to banded quartzite (9406), with but little new mineral formation. Other more basic types have been baked to dark-green epidotic hornstones.

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[1] This dyke is described by Bryce ('Geology of Arran,' 4th edition, 1872, p. 79), but he does not notice the alteration of it due to the granite.

[2] This mineral appears to be cordierite with well-developed sector twinning. G.W.T.

[3] E. B. Bailey, 'Domes in Scotland and South Africa : Arran and Vredefort,' *Geol. Mag.*, vol. lxiii., 1926, p. 486.

Similar induration effects, epidotization, and discharge of the natural brown and red colours of the Old Red Sandstone in favour of greenish and greyish tints, may be noted in the Glen Rosa section, although a band of schist a quarter of a mile thick intervenes between the granite and the Old Red Sandstone. The schist becomes spotted with contact minerals at least 150 yards from the granite margin. Near the confluence of the Garbh Allt with the Rosa Burn there is coarse spotting in a dark hornfels, and half-inch prisms and needles of andalusite become visible on smooth waterworn surfaces. Cordierite is also occasionally developed here, as also in the schists at the contact exposed in the Garbh Allt.[1]

Dr. A. Harker [2] has described basaltic dykes metamorphosed by the northern granite near the contact exposed in the Cnocan Burn, north of Brodick. His account is as follows :—

'A specimen taken in actual contact with the granite shows in a hand-specimen no noticeable peculiarity, but in a thin slice (7442) it is seen that each ophitic plate of augite has been transformed into an aggregate of green hornblende. Occasionally a flake of brown mica is seen, usually clinging about a grain of magnetite. There is no indication that either the felspar or the iron-ore of the original rock has suffered any change, and the metamorphism is thus not of an extreme kind. Two dykes 60 or 70 yards from the granite in Glen Sannox Burn, one a dolerite, the other probably an augite-andesite, show a lower grade of metamorphism, the augite being replaced partly by little blades of green hornblende but partly by chlorite (9416, 9417).'

The most noteworthy feature in the contact metamorphism induced by the northern granite in the surrounding rocks is the differing grades of the alteration as it affects the Old Red Sandstone and the Dalradian schists respectively.[3] The latter show a considerable degree of induration, hornfelsing, and new mineral formation. Within 100 yards of the granite margin new-formed biotite is common ; closer in, andalusite and cordierite make their appearance. On the other hand the Old Red Sandstone (with one exception, *see* above, p. 157) has undergone little or no mineral change. It has been indurated and epidotized to short distances from the contacts.

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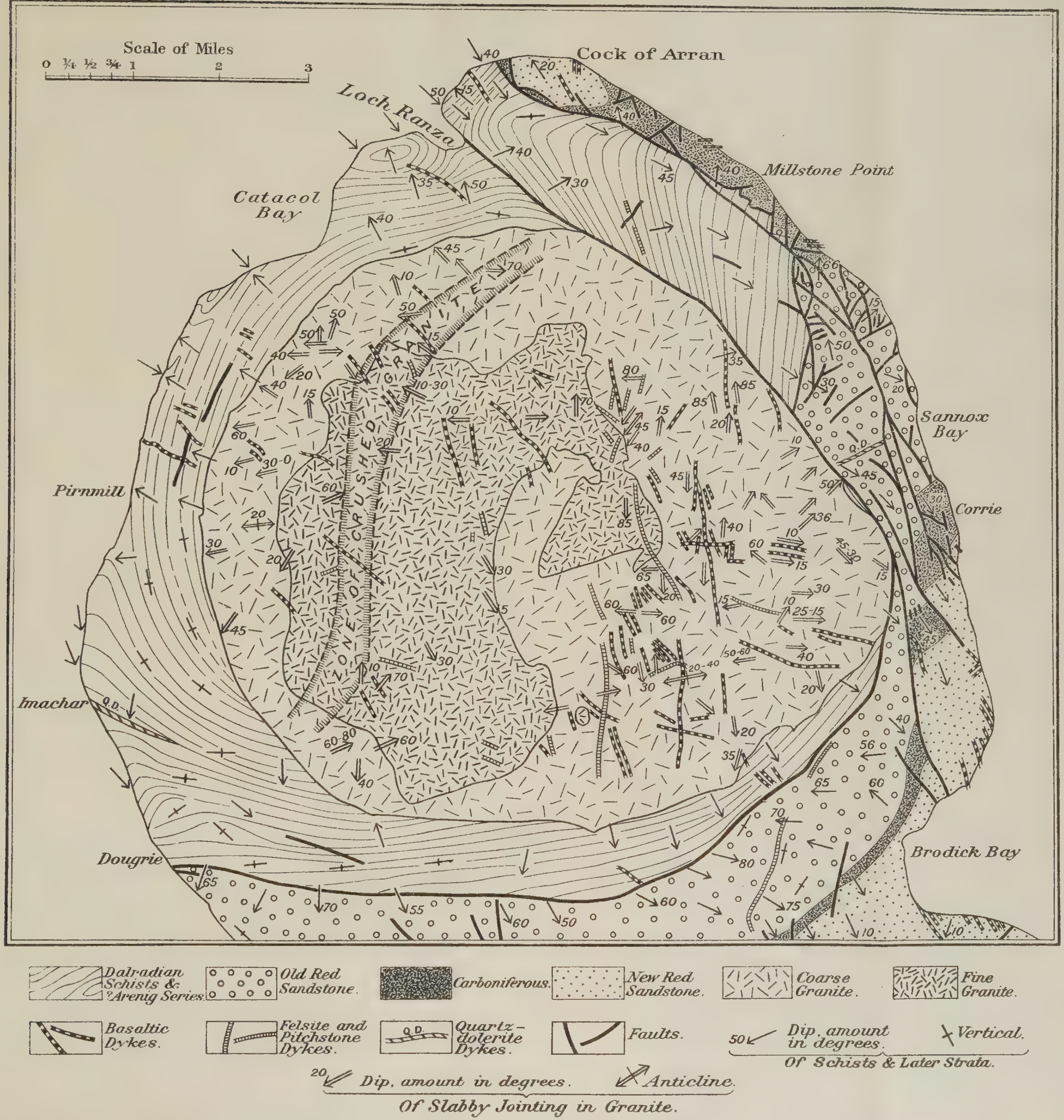
[1] Dr. W. Mackie (personal communication) has recently found blue corundum in the hornfels on the margin of the granite.

[2] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 117.

[3] G. W. Tyrrell, 'Excursion to Arran,' *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, pp. 407–408.

TECTONIC MAP OF NORTH ARRAN.



Geological Boundaries, Faults, etc. after W. Gunn and E. B. Bailey.
Dips of Slabby Jointing in Granite, and Zone of Crushed Granite, after John Smith.

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H.M.S.O.Cr.

One explanation of these facts is based on the different stratigraphical and structural positions of the Dalradian and the Old Red Sandstone with respect to the granite intrusion. The granite magma may have come into contact with the deep-seated Dalradian rocks when it was highly heated and gasified ; but when it reached the more superficial Old Red Sandstone horizon it was at the final stage of intrusion, and was thermally moribund owing to degasification and loss of heat.[1]

An alternative explanation is that the granite magma never came into actual contact with the Old Red Sandstone at all (at any rate, at the horizon of present-day exposures), and was always separated from it by a band of schists, with the result that the Old Red Sandstone was always at the remote periphery of the contact aureole. The actual contact of granite and Old Red Sandstone in the White Water, Corrie, is due to faulting. This explanation is supported by the fact that the Old Red Sandstone is altered in the same way, and to the same degree, whether it is in contact with the granite or separated from it by schist. G.W.T.

TECTONICS AND MODE OF INTRUSION

The intrusion of the northern granite and of the neighbouring Central Ring Complex, with the attendant disturbances of the adjacent strata, supply the clues to the tectonic structure of practically the whole of Arran. The late W. Gunn, with his usual perspicuity, noticed the connection between the intrusion of the granite and the general steep outward dip of the adjacent sediments, as is shown by the following quotation :—

‘ On the southern side of the great granite mass, if we compare the dip and strike of the rocks near Brodick Castle and in Glen Shurig with those in the Shiskine district, we find that the Upper Old Red, the Carboniferous, and the Lower Triassic beds have all been nearly equally affected by upheaving or disturbing movements, so that these movements must have been very considerable since the Triassic period. And when we notice a general parallelism between the successive outcrops of these beds and the edge of the great granite mass we are driven to the conclusion that the intrusion of the latter has been the principal factor in causing the present arrangement of the strata in question.’ [2]

The whole question has recently been thoroughly discussed by Mr. E. B. Bailey,[3] who has instituted an instructive comparison between the Arran granite uplift, and the similar but greater phenomena of the Vredefort Dome,[4] and has published a map and section illustrating the connection between the Arran intrusions and the tectonics of the island. This map has been freely drawn upon in preparing the tectonic map of North Arran (Plate III).

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[1] G. W. Tyrrell, *ibid.*, p. 408.

[2] ‘ Geology of North Arran, etc.’, (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 132.

[3] ‘ Domes in Scotland and South Africa : Arran and Vredefort,’ *Geol. Mag.*, vol. lxiii., 1926, pp. 481–495.

[4] A. L. Hall and G. A. F. Molengraaff, ‘The Vredefort Mountain Land in the Southern Transvaal and Northern Orange Free State,’. *Verh. d. Kon. Akad. v. Wetensch., Amsterdam* (2), Deel xxiv., No. 3, 1925.

In an early paper which has been frequently overlooked Mr. John Smith[1] put forward a novel and ingenious view of the intrusion of the North Arran granite, based on extensive observations of the dip of the slabby jointing or sheeting. He showed that while the granite slabs dipped outwards towards the schists all around the margins of the mass, in the interior they were arranged in anticlines and synclines corresponding respectively with the mountain ridges and the intervening valleys (*see* map, Plate III). He noticed that near the margins of the intrusion the igneous rock became fine grained, and the sheeting unrecognizable; but as he ascribed the jointing to pre-consolidation causes he was led to the hypothesis of the forcible upthrust of the solid granite to account for the observed phenomena, as is shown by the following quotation:—

'It is even possible, and indeed even probable, that the granite slabs, while still red-hot, were considerably increased in dip as the rock first began to be moved upwards; but a time would come when this ceased, and when the granite was quietly but forcibly squeezed up through the slate, turning it up on edge, or shearing up through it, as at the north side of the granite area. It was during this period of its history that the surrounding zone of fine-grained granite [*i.e.* the contact zone] was formed by remelting from excessive friction, and the contained belt of confusedly-jointed rock was produced by the granite being crushed, and the individuality of the slabs destroyed.'[2]

Smith's main thesis is that the present surface of the granite is near its original surface, which, during the slow rise of the viscous magma, took the mould of the overlying schist roof, the synclines of schist occupying the glens, and the anticlines overarching the ridges.[3] The slabby jointing or sheeting is then the expression of the cooling of the granite against the mould of schist. The fatal objection to this view is that the valleys and ridges should run north-east to south-west parallel to the original strike of the schists which then overlay the granite; whereas the only main glens which run in this direction are the upper parts of the Sannox Burns, and the lower part of the Iorsa. In these, however, the synclinal arrangement of the sheeting is poorly displayed or absent; whereas it is magnificently developed in valleys which, like Glen Rosa, run athwart the original strike direction of the schists.

As a matter of fact, the joint-system of the Arran granite was developed long after consolidation, and is mainly due to well-defined tensional stresses (p. 162). The slabby jointing or sheeting which is so apparent at the surface, but little displayed in deep section, is, in all probability, mainly an exfoliation effect, due to temperature variations operating from, and producing rifts parallel to, the present surface of the ground.[1]

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[1] 'A New View of the Arran Granite Mountains,' *Trans. Geol. Soc. Glasgow*, vol. x., part ii., 1896, pp. 216–256.

[2] *Op. cit.*, p. 254.

[3] *Op. cit.*, Fig. 22, p. 255.

On the western side of the granite mass Mr. Smith has mapped a zone of crushed granite extending in a general north to south direction from Glen Catacol to Glen Scaftigill, both of which run for some distances along this zone, and have evidently been guided by it. The belt of crushing bends to the north-east beyond Glen Catacol, and disappears near Glen Easan Biorach. At the south end of the belt there is a correlative twist towards the south-west (*see* map, Plate III).

The structure of the rocks surrounding the granite is clearly dependent on the intrusion, for in general, as Gunn pointed out, the strikes of the adjacent rocks curve in conformity with the granite margin, and their dips are outward and steep for some distances from the margin. Mr. E. B. Bailey (*op. cit. supra*) has dealt with the structure in detail; and the map (Plate III) summarizes the observations that have been made by Gunn and by him. A section across the south-eastern edge of the granite mass shows that the adjacent rocks, schists, Old Red Sandstone, Carboniferous, and New Red Sandstone alike, have been sharply uptilted to a distance of 1¾ miles from the margin. A section across the south-western margin shows similar features (Fig. 21).

From analogy with the flat-lying Mesozoic rocks of the Hebridean and Antrim regions, and the absence of angular unconformities within them and the post-schist sediments of Arran, it is concluded that the latter were gently inclined until the intrusion of the granite, and that the steep dips are consequently of Kainozoic date.

The granite appears to have been intruded into an almost complete ring of Dalradian schists, the strike of which was originally north-east to south-west, congruous with the strike in the neighbouring parts of Cowal and Kintyre. The dip of the schists was predominantly south-easterly. Hence the intrusion of the granite merely steepened the dip on the south-east margin, where the schists were already dipping outwardly from the granite. In Glen Rosa there appears to have been actual overturning of the Old Red Sandstone, which in places dips towards the granite. On the north-west side the schists were dipping towards the granite, and the uplift produced by the granite, which was firmly welded to the schists, has resulted in the fine synclinal structures of the Catacol and Lochranza region[2] (Fig. 21).

On the western and south-western sides of the granite the schists have been dragged round by the uplift, so that the strike swings into approximate parallelism with the margin. Only on the north-eastern side of the granite does the schist preserve its original strike in some measure, so that it meets the granite contact at an angle approaching a right angle. Here apparently, the conditions were such that the granite failed to get a grip on the schists, so to speak, and the upward stresses were relieved by faulting, not by bending. In other words, the granite burst its cover on the north-eastern side. Mr. E. B. Bailey[1] has shown that in this region the granite is bounded by a great fault, along which marked mylonization effects are to be noted in the White Water section (p. 157). He has continued this fault along the north-eastern edge of the granite, where its extension to the north-west coincides in a remarkable way with the straight eastern shore of Loch Ranza. Southward this fault is made to join up with the curved fracture separating the schists from the Old Red Sandstone on the southern side of the granite (Plate III). Alternatively the faulting on the north-east and east sides may be explained by the hypothesis that part, at least, of the complicated fault-zone adjacent to the granite on this side (*infra*) pre-dated the granite, and that the latter thus found it easier to make room for itself by continuing the fracturing thus initiated.

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[1] *See* T. N. Dale, 'The Commercial Granites of New England,' *Bull.* 738, *U.S. Geol. Surv.*, 1923, pp. 26–36.

[2] E. B. Bailey, *op. cit.*, p. 490. *See* p. 21 of this Memoir. Mr. John Smith also recognized the Lochranza syncline, *op. cit.*, Fig. 9, p. 233.

It is further to be observed that only in this north-eastern region does the granite come into contact with the Old Red Sandstone. It is inferred that the uplift, taking place here by faulting instead of bending, ultimately brought the granite into contact with the Old Red Sandstone overlying the schists (Fig. 21).

Another remarkable feature which is to be correlated with the foregoing is the occurrence of an extremely complicated zone of faulting on the north-eastern and eastern sides of the granite. The disturbed area includes all rocks from the schists to the New Red Sandstone, and is dominated by fractures running in a general north-west to south-east direction, with subordinate lines directed nearly north to south, and east to west. On the northern, western, and southern sides of the granite there are but few faults, and these are concentric with the granite margin (map, Plate III). Beside the major fault separating the schists from the Old Red Sandstone on the south, W. Gunn mapped a fault running parallel to the granite margin about 2 miles east of Dougrie, and another two to the north-east of Pirnmill. Because of their strike at an angle to the granite margin, and their possible earlier fracturing in the Kainozoic directions (especially north-west to south-east), the rocks on the north-east side were structurally weak in relation to the stresses generated by the rising granite magma, and gave way by means of extensive faulting in both tangential and radial directions to the granite margin.

Attention may be here directed to the post-consolidation tensional stresses imposed upon the granite, as evidenced by the directions of the jointing features, and of the dykes intersecting the mass. Much work remains to be done in determining the directions of the joint-systems, as the only data available, those due to John Smith,[2] refer solely to the slabby surface jointing or sheeting. It is probable that the vertical joint-systems will be found to conform to the dyke directions. On reference to the map (Plate III) it will be observed that the dykes run in three main directions; approximately north-west to south-east, north to south, and east to west, directions which, as seen above, are represented in the faulting of the adjacent rocks, and in the zone of crushing on the western side of the granite. Felsitic and basaltic rocks fill rifts in each of these directions indifferently, although basalts are predominant in the north-west to south-east direction, and felsites in the north to south direction. The relative ages of these dyke directions and injections are as yet unknown, and further work is needed before the above observations can be turned to account in determining the tectonic conditions of Kainozoic times in the Clyde area according to the methods of Cloos and his school.[1] The subject is again discussed in a later chapter (p. 245).

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[1] *Op. cit.*, pp. 486, 488.

[2] *Op. cit. supra.*

A further question remains as to the mode of intrusion of the granite mass, and the relations of the fine-grained to the coarse-grained variety. The fine-grained variety is known to be intrusive into the coarse-grained, but its three-dimensional shape is unknown. In the Vredefort boss a later plutonic mass, represented only by small outcrops at the present surface, has uplifted a cover consisting of sediments and an even older granite.[2] In the Arran example, however, the granite is intrusive into the sediments, and a somewhat younger mass has been injected into it. What were the parts played respectively by the older and coarser, and by the younger and finer granites in causing the peripheral disturbances ? In the absence of data regarding this question Mr. E. B. Bailey (*op. cit. supra*) rightly treats the northern boss as a single unit. He also shows that there has been very little lateral displacement of the adjacent rocks, as indicated by the absence of concentric folding such as there is around the Mull plutonic focus.[3] A great bulk of schist, however, has been displaced by the Arran granite, beside that constituting the lifted cover, now lost by erosion, and consequently the granite must have made room for itself either by stoping, by the subsidence of a cylindrical plug (as, for example, in the Glen Coe region), or perhaps by a combination of these two processes. It may be noted in this connection that the contact of the Arran granite with the adjacent rocks is sharp and clean-cut. Accidental inclusions of the country-rocks are rare even at the margins.

The outcrop of the granite is approximately circular, and it may be inferred from this that we are dealing with a deep-seated cross-section of a cylindrical subsidence filled with granitic magma. It may be conjectured that the process of uplift, with the consequent flexuring of the cover around the periphery of the mass, was initiated and continued to some extent by the coarse granite ; and that the process was carried on to its ultimate end, with probably shattering of the cover, and of the adjacent rocks on the north-east side of the mass, by the intrusion of the fine-grained granite. On this view the present outcrop of the fine-grained granite represents the roots of a ring intrusion similar to that of the adjacent Central Ring Complex, with which it also presents great petrographical similarity. The latter, however is cross-sectioned at a considerably higher horizon than the northern boss, and remnants of its split, riven, and shattered cover are still preserved, as well as traces of the volcanic rocks which were erupted at the surface (*see* succeeding chapter). Profound erosion has bitten so deeply into the northern mass that all signs of its shattered cover, and of the probable superficial rhyolites and felsites, have long been removed ; and the only fracture that is now visible is the long and deep-seated rent on its north-eastern border.[1]

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[1] H. Cloos, ' Tektonik und Magma, Bd. 1,' *Abh. d. Preuss. Geol. Landesanst.*, N.F., 89, Berlin, 1922, and ' Das Batholithenproblem,' 1923. *See also* R. Balk, *Bull. Geol. Soc. America*, vol. 36, 1925, pp. 679–696 ; G. W. Tyrrell, *Science Progress*, October 1925, pp. 211–213 ; ' The Principles of Petrology,' 1926, p. 44.

[2] E. B. Bailey, *op. cit.*, pp. 491–494.

[3] *Mull Memoir*, 1924, Chapters XII., XIII.

If the North Arran granite has uptilted adjacent rocks as far up as the lower part of the New Red Sandstone, additional evidence is thereby supplied of its Kainozoic age, previously based on petrographic comparison with the post-Mesozoic granite of the Mourne Mountains, and with the granite of the Central Ring Complex, which cuts a breccia containing blocks of Cretaceous limestone. G.W.T.

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[1] This view was foreshadowed by W. Gunn. *See* 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 90.

CHAPTER XIV

THE KAINOZOIC IGNEOUS ROCKS (*continued*)

The Central Ring Complex

INTRODUCTION

The great discovery by W. Gunn in 1900 [1] of a large and complicated oval area consisting of fragmental rocks with numerous igneous masses, in the central part of the island, caused a notable advance in the interpretation of Arran geology. The included masses of Rhætic, Liassic, and Cretaceous strata within this area (Chapter X.), provided confirmation of the Triassic age of some of the associated rocks in the southern half of the island, and demonstrated for the first time the Kainozoic age of the large granite masses of Arran. Gunn's description of this area as a ' volcanic vent ' is undoubtedly too simple to explain all the facts ; but unquestionably a volcanic pile rose over part of the area, and tremendous explosive activity accompanied the intrusion of the acid rocks. Following upon the demonstration of ring complexes in Mull,[2] Ardnamurchan, and Skye, as characteristic features of igneous episodes of the same age as that of Arran, there appears to be no doubt that, in this ' volcanic vent,' we really have to deal with a ring complex which, while less perfectly preserved than those of the above-mentioned centres, had as long and as complicated a history.

Prof. J. W. Gregory has recently advanced in brief outline a new theory of the origin of the central complex.[3] He regards the ' agglomerate ' as consisting of (1) sedimentary conglomerates and breccias containing igneous fragments, some of which have been derived from Palæozoic lavas ; (2) intrusive breccia, due sometimes to flow-brecciation, but usually to the intrusive rock having enclosed quartz and fragments of sedimentary and igneous rocks, these breccias resembling those of the Loch Bà region of Mull ; and (3) normal tuffs and agglomerates. His reading of the history of the central complex is as follows : the granite forming the base of the Ard Bheinn group was intruded into the Old Red Sandstone, upon which rested some Mesozoic strata. All these beds were upheaved into a dome, which was then eroded so deeply that the granite was ultimately exposed. The sedimentary breccias and conglomerates formed by the denudation of the dome had the characters of talus, and were composed of irregular alternations of sandstone and boulder beds. A complicated series of minor intrusions, mostly acid, were at the same time injected into the granite, and fragments of all these rocks were carried into some of the later conglomerates. The granite had been preceded by gabbro on the eastern margin, and was invaded by a horseshoe belt of basic dykes around the western part. These dykes, which were accompanied by volcanic eruption on the western side of the area, caught up quartz-pebbles from the Old Red Sandstone, and fragments of the earlier acid intrusions.

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[1] ' Summary of Progress for 1899,' *Mem. Geol. Surv.*, 1900, p. 133. Fuller descriptions are to be found in ' Summary of Progress for 1900,' *Mem. Geol. Surv.*, 1901, pp. 123–126 ; *Quart. Journ. Geol. Soc.*, vol. lvii., 1901, pp. 226–243; and ' Geology of North Arran, South Bute, and the Cumbraes,' (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 79.

[2] *Mull Memoir*, 1924, Chapters XV., XVI.

[3] *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, p. 410.

This reading, while requiring correction in some of the details, has been of great service in leading up to what is believed to be the true interpretation of the complex. The chief features which led the writer to believe that in the 'central volcanic vent' of Arran, we are dealing with a ring complex of the Mull type, are :—

(1) The arcuate and annular shapes of many of the outcrops.

(2) The recognition of the fact that many of the supposed intrusive masses, especially on the western side of Ard Bheinn, are really pre-breccia in age, and are remanié masses which contribute fragments to the breccia in increasing proportion as their margins are approached.[1]

(3) The induration and epidotization of the breccia, a phenomenon absent from the later granite, but present in the earlier gabbro intrusions and remanié masses. This feature is entirely similar to the 'pneumatolysis' (better termed propylitization) effects around the ring complex of south-eastern Mull, and to the effects already noted around the northern granite (p. 33).

So far, detailed mapping in the light of the ring-complex theory has only been carried out over the eastern part of the area, although many traverses have been made over the whole region. The continuation of the mapping will doubtless afford many new corroborative facts.

A tentative history of events in the central region may now be outlined (Plate IV). Igneous activity is believed to have begun beneath a cover consisting of Old Red Sandstone and Mesozoic rocks, with a magma of basic character giving rise to lava-flows. Remnants of these lavas are preserved in the screen of basaltic rocks entirely similar to the plateau basalts of Skye and Mull, which forms the elongated, narrow, arcuate outcrop on the western side of Ard Bheinn. These flows proceeded from an undersaturated magma, whose hypabyssal representatives are the crinanite sills of south-eastern Arran. The sedimentary cover was probably uplifted into a dome-shaped form, and its shattering was initiated at this stage of activity.

An over-saturated magma now appears to have been generated, a basic phase of which was intruded as the incomplete rings of gabbro on the eastern margin of the complex. These rings were originally more extensive than they are at present, as is shown by remnants on the northern edge of the complex, and by the presence

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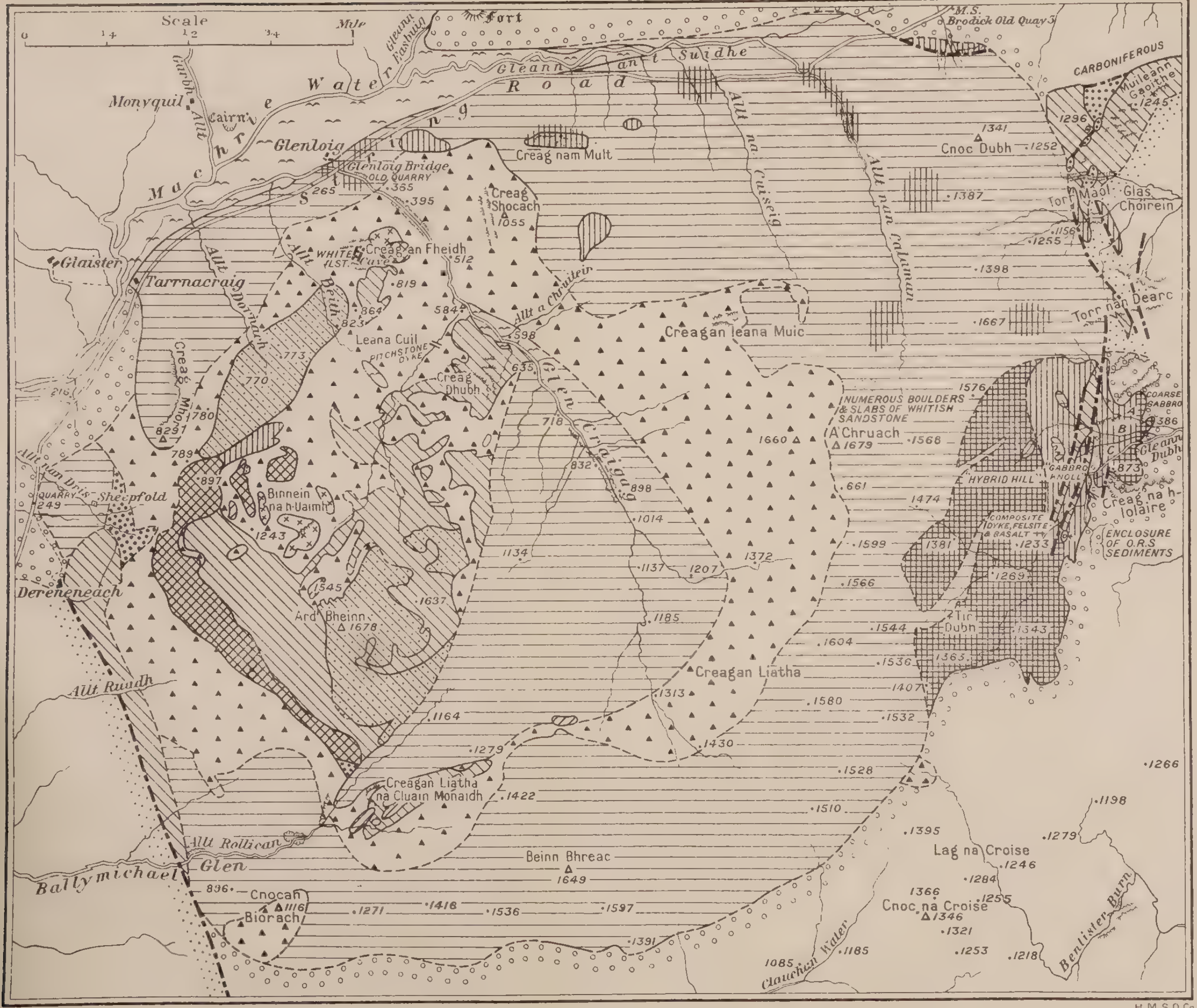
[1] This line of attack on the problem was first suggested by Mr. E. B. Bailey who, after traversing the area in company with me, entirely concurred in the ring-complex interpretation.

MAP OF CENTRAL RING COMPLEX IN ARRAN.



INDEX TO PLATE IV

▧	Post-breccia Felsites. Granophyres, and acid rocks of doubtful status.	▩	Pre-breccia plateau-basalt.
▤	Granite.	⁘	Mesozoic fragments within Ring Complex.
▦	Diorites and mixture-rocks.	░	New Red Sandstone on margin of Ring Complex.
▲	Explosion-breccia.	○	Old Red Sandstone on margin of Ring Complex.
▨	Basalts, etc., of doubtful status.	⌒	Alluvium.
×	Pre-breccia felsites and granophyres.	— · — · —	Fault.
▥	Gabbros and other basic plutonic rocks.		Later basalt dykes, etc., omitted.

of dioritic mixture-rocks at various places on the east and north. A long series of acid intrusions was then injected, some of granite, *e.g.* the broad outcrop which forms an almost complete ring around the area, and the central plug (Glen Craigag). Other facies were felsitic in character. The interaction of the granite with the eastern gabbro produced an interesting series of dioritic mixture-rocks (p. 175). Great explosive action accompanied some of the acid intrusions, shattering the cover into large and small fragments, and thus giving rise to the breccia which now occupies a large part of the area. The explosive action was, no doubt, variable in its intensity in different places; large fragments of the cover escaped complete brecciation, and, although fissured and upturned, nevertheless preserved something of their original characters and attitude. Some of the acid magma may have reached the surface, and formed the small rhyolite masses which are found on Ard Bheinn.

The intrusive and explosive actions were concomitant, and both took place along arcuate fissures, which may or may not have been connected with caldera formation at the surface. One well-marked arcuate line of faulting and brecciation traverses the Glen Dubh gabbro, and a multiple dyke of felsite and basalt has risen along the line of weakness, the felsite being accompanied by further explosive action. The continuation of this feature to the north traverses the eastern margin of the granite, and has produced some shattering and mylonization in that rock. The arcuate nature of the faulting is also shown by the occurrence of curved screens of the country-rock, separating adjacent intrusions, as in the Glen Dubh area; or separating agglomerate and felsite, as on the western side of Ard Bheinn (Plate IV).

The sequence of events was completed by the injection of a final series of acid intrusions, definitely later than the breccia. This series includes the north-eastern felsites, the granophyres to the south and south-east of Tarrnacraig, and the felsite and granophyre near Derenenach.

This interpretation differs from Prof. Gregory's in recognizing the priority of basic extrusions and intrusions; in regarding the fragmental materials as due entirely to volcanic explosion; and in the fuller recognition of Kainozoic pre-breccia igneous masses which have contributed material to the breccia.

The writer agrees with Prof. Gregory in deprecating the extended use of the term ‘agglomerate’ for the fragmental material. If the term ‘agglomerate’ means coarse, fragmental material, consisting largely of lavas, formed in and near a volcanic vent, then the fragmental rocks of the central complex are not agglomerates in this sense. The term *explosion-breccia*, indicating the material formed by the shattering of a sedimentary cover (in this case), and by the auto-brecciation of the invading igneous rock that caused the explosive action, appears best to describe the nature and origin of the material.

The date of the Central Ring Complex seems to be definitely later than the northern granite; for the north-eastern margin of the outer granite ring clearly truncates the strata of the Old Red

Sandstone, the Carboniferous, and the New Red Sandstone, which were uptilted by the intrusion of the northern boss.

FIELD-RELATIONS AND PETROGRAPHY

The Central Ring Complex occupies an oval area almost exactly in the centre of the island, its northern boundary just touching the String Road which connects Brodick and Machrie Bay (Plate IV). Its greatest extension is about 4 miles in a west-south-west direction from Windmill Hill to Ballymichael Glen ; and its greatest width in a north-north-west to south-south-east direction from Glenloig to Beinn Bhreac is about 2¾ miles. Its area is estimated at 7 square miles ; and it embraces the high plateau ground which culminates in Ard Bheinn (1676 feet), Beinn Bhreac (1649 feet), A' Chruach (1679 feet), and Cnoc Dubh (1341 feet). The Central Ring Complex is geologically very complicated, and forms very rough, craggy ground especially near its margins. The central part contains large areas of peat which unfortunately conceals the relations of the rocks at some critical points. The principal features will be dealt with in the following order, and the petrographical descriptions will be appended for convenience to the sections treating the different rock groups :—

1. Glen Dubh gabbro, and associated rocks.
2. Basic remanié masses included within the explosion-breccia, or enveloped in granite.
3. The explosion-breccia ('agglomerate'), with the associated felsites and rhyolites.
4. The main granite and granophyre, and the associated quartz-diorite and diorite.
5. The late acid intrusions.

I. THE GLEN DUBH GABBRO AND ASSOCIATED ROCKS

A. Field-Relations

The rocks included within the boundaries of this mass are Lower Old Red Sandstone, gabbro, granite, dioritic mixture-rocks and hybrid rocks, granophyre, and felsite veins (map, Fig. 22, and section, Fig. 23). Of these, the granite occurs on the western margin of the mass. It is believed to have been injected into incomplete ring intrusions of coarse gabbro, with the formation of dioritic mixture-rocks and hybrid rocks, which now occupy the major part of the area, the gabbro forming large enclosed remnants. Originally the gabbro seems to have been intruded as two large ring dykes (Fig. 23), separated by a narrow screen of Lower Old Red Sandstone. Later pulses of acid intrusion have sent veins of granophyre and felsite far and wide through all the rocks of the complex. Accompanying the later granitic intrusions were arcuate faults, one of which occurs between 'Gabbro Knoll' (Fig. 22) ring dyke and the adjacent screen of Lower Old Red Sandstone. The fault-plane has been occupied by a multiple dyke of felsite and basalt. Another fault-plane probably accompanies the felsite intrusion on the western side of 'Gabbro Knoll' (Fig. 23).

The map, Fig. 22, and the section, Fig. 23, summarize the

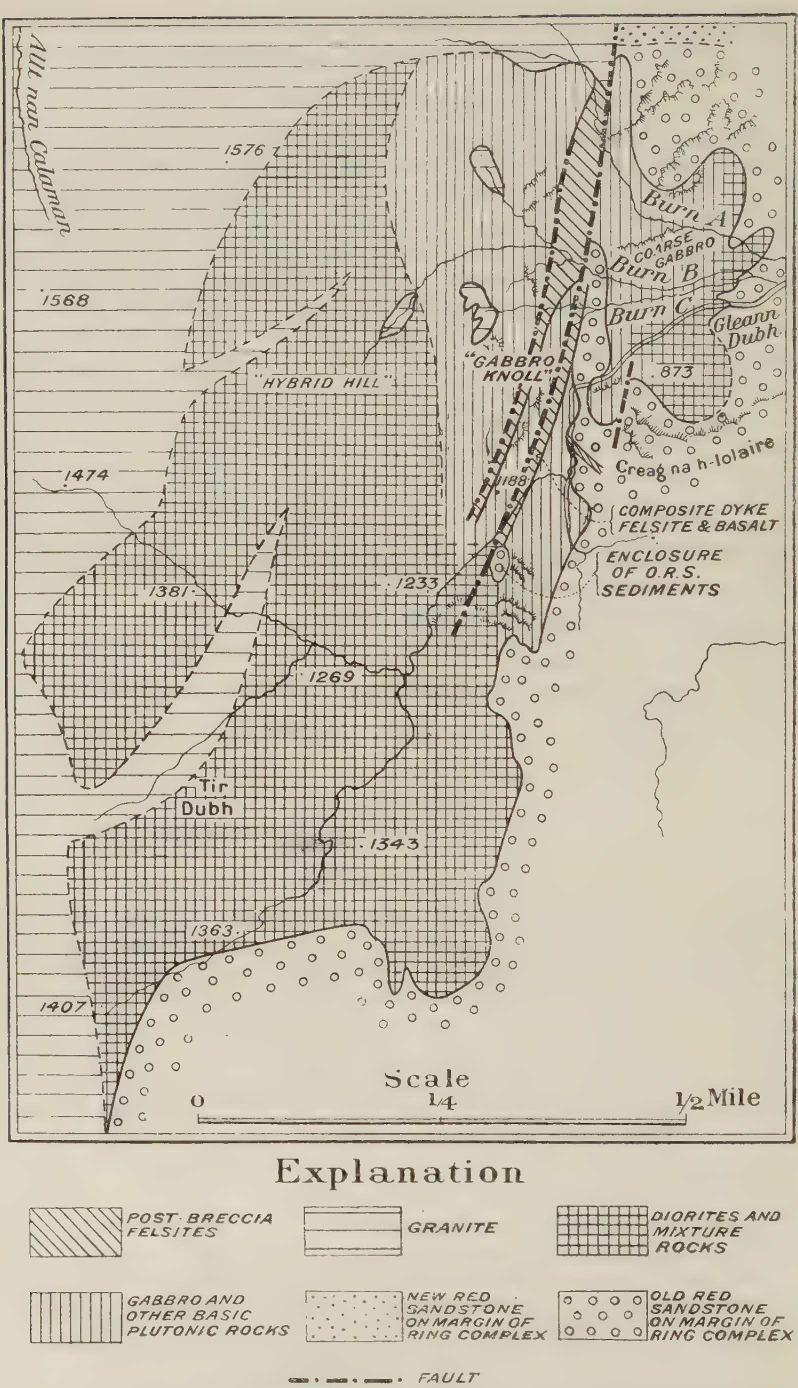


FIG. 22.—*Geological map of head of Glen (Gleann) Dubh, illustrating the detail of the eastern edge of the Central Ring Complex.*

details of the field-relations of the various rock components of the mass. The best-exposed portion of the complex occupies the corrie at the head of Glen Dubh, and splendid sections are afforded by the Glen Dubh Water and its northern tributaries. The contact of the intrusion with the baked Old Red Sandstone can be but roughly located in the Glen Dubh Water at the foot of the corrie. The contact is intricate, and there is much veining and interpenetration of the sediments by the igneous rock. The weathering of the two kinds of rock is so closely similar that it is a very laborious task to discriminate the junctions. Much of the Glen Dubh section up to near the 873 feet O.D. is in a dark, fine-grained, dioritic rock, which is profusely veined with aplite and granophyre. Irregular remnants of the Old Red Sandstone country-rocks are also to be found. Under the cliff of Creag na h-Iolaire the igneous rock is mainly of an acidic type. On the south side of the gorge, near the right-angle bend in the burn, a coarse olivine-gabbro is found, and a small fault parallel to the larger arcuate faults to the west can be traced. This mass of gabbro can be followed to the north across the northern tributaries of Glen Dubh. It is especially prominent in a steep scarp between burns A and B (Fig. 22), whence the analysed rock was taken (p. 174). The intrusion passes under baked Old Red Sandstone in the prominent unnamed hill immediately north of Burn A, and, just as on the eastern side of Glen Dubh, the contact rock is of a distinctly acid facies.

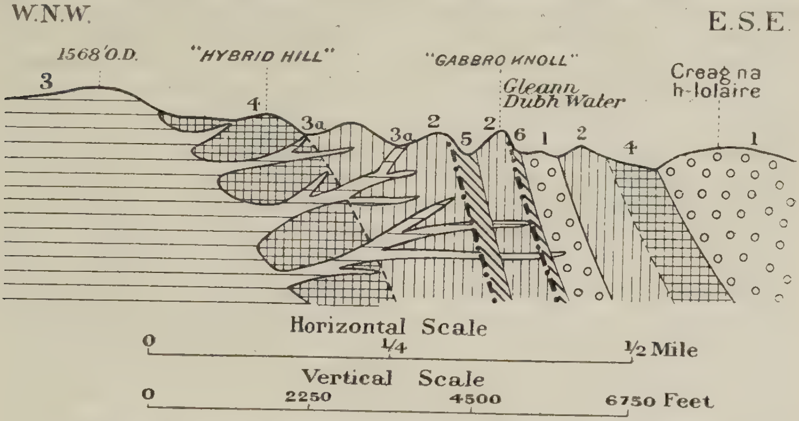


FIG. 23.—*Section across eastern edge of Central Ring Complex.*

1. *Lower Old Red Sandstone* ; 2. *Gabbro* ; 3. *Granite and granophyre, with 3a, veins and dykes* ; 4. *Granite-gabbro mélanges, hybrid rocks, diorite and quartz-diorite* ; 5. *Felsite intrusion* ; 6. *Fault, with composite dykes of felsite and basalt.*

At the right-angle bend in the burn opposite 'Gabbro Knoll' a broad screen of Lower Old Red Sandstone occurs. On its western edge there is a constant horizon of green quartzitic breccia, which can be traced northward across the northern tributaries. Next to it there is a greenish, silty, quartzitic rock which is so fine grained as to exhibit cleavage like a slate. This sedimentary screen can be traced north across Burn B (Fig. 22), but fades out to the north of the burn.

The junction between this screen and the gabbro of 'Gabbro Knoll' is a faulted one. Both gabbro crush-rock and Old Red Sandstone crush-rock can be found along it, and both are highly epidotized, as are also both the adjacent solid rocks. The zone of weakness is occupied by a multiple dyke of felsite and basalt. A good section of the fault-zone, and of the multiple dyke, is afforded by a branch of Burn C, immediately north of the right-angle bend in the Glen Dubh Water. Here the felsite, which carries visible quartz, is 14 feet thick, and the spheroidally-weathering basalt is 8 feet thick. There is some appearance of brecciation within the felsite itself, and this may be due to explosive action attending its intrusion.

Immediately west of the sedimentary screen there comes the prominent scarp of 'Gabbro Knoll,' consisting of coarse quartz-gabbro. Traced to the north this mass fades out just before Burn B is reached. To the south it passes gradually into the dark, fine-grained, dioritic facies. On the western side of 'Gabbro Knoll' a sharp vertical intrusive junction of felsite against gabbro is seen. The felsite intrusion occupies the valley between 'Gabbro Knoll' and the next scarp to the west. It can be traced northward across the tributaries, and appears ultimately to join up with the fine-grained margin of the main mass of granite (Fig. 22). It appears to have been injected along the line of the arcuate fractures, and in Burn A can be seen intruded against the shattered western edge of the gabbro. To the south the outcrop diminishes in width and finally disappears.

To the west of the felsite there is a broad, heterogeneous mass consisting of coarse gabbro, and the fine-grained dioritic facies, intermingled with, and interpenetrated by, large and small masses of granite and granophyre. This zone is well exposed in the headwaters of the Burns A, B, and C (Fig. 22). To the south the zone passes gradually into the large area of dioritic rocks which occupies the southern half of the Glen Dubh mass. In the district known as Tir Dubh, the massive rock of the knolls is pierced by many little acid strings and granite veins.[1] At the head of Burn C, there are fine exposures of xenolithic and hybrid rocks, showing gabbro and diorite fragments enclosed and partially dissolved in granophyre.

Intervening between the last-mentioned gabbro and diorite zone and the main granite ring, and also occupying the southern half of the basic mass, there is a very heterogeneous region of gabbro-granite mixture-rocks. xenolithic and hybrid types, and also of quartz-diorite and diorite in which no traces of mixture or hybridism can be detected. The finest exposures of xenolithic and hybrid rocks are to be seen on a hill about a quarter of a mile due west of 'Gabbro Knoll,' which has been named 'Hybrid Hill' (*see* Fig. 22). The petrographic evidence renders it probable that the pure, homogeneous diorite and quartz-diorite are the final results of the complete solution of the gabbroidal rocks within the granite magma. All stages in the process can be studied in the field and under the microscope.

Resuming the section in the Glen Dubh Water at the summit of the corrie, we find the junction between the gabbro and the sedimentary screen runs along the stream for some distance. South of the right-angle turn near 'Gabbro Knoll,' an intrusive mass of felsite is seen on the eastern side. The composite dyke can be again followed for some distance along the main western headwater of the burn. On the south-east side of this stream, west of 1233 feet O.D., there is a patch of quartz-conglomerate and white sandstone, with some cherty greywacke, entirely surrounded by gabbro. Above this point the gabbro seen in the stream is fine grained with a granulose texture, and has a nearly horizontal sheeted structure which gives it a bedded aspect, and causes a small waterfall. G.W.T.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 96.

The alteration effected by these igneous masses on the adjoining sedimentary strata is very great. Along the north side of the oval the actual junction of the igneous rocks with the Old Red Sandstone is not visible, and there is no opportunity of studying the altered rocks, but on the south and east sides the effects are marked. The red sandstones and conglomerates of the Trias and Upper Old Red Sandstone have their colour changed to white and the rocks are converted into quartzites, while the more felspathic sandstones of the Lower Old Red formation are changed from a chocolate to a grey or bluish colour, their bedding sometimes is nearly obliterated, and the rock is very tough and hard. The chocolate mudstones of the same formation are in like manner altered to flinty rocks resembling porcellanite. W.G.

Examples of these baked sediments are represented in the Survey collection (24352–3). The first of these slices shows angular grains of quartz embedded in an abundant quartzose matrix of silt grade. Numbers of minute, colourless, highly-refracting grains, which appear to be some form of pyroxene, have been developed by the contact metamorphism, along with epidote. Biotite flakes have been formed in argillaceous portions of the matrix, and specks of iron-ores have been segregated into small clouds. Slice (24353) is a baked argillaceous sediment of quartzo-micaceous composition, which shows remarkable micro-brecciation and faulting, and is epidotized along some of the crush bands.

B. Petrography

Dr. A. Harker's description of the gabbroid rocks at the head of Glen Dubh is as follows :[1]—

'A good example of these normal *quartz-dolerites* comes from the north side of Glen Dubh. It is of quite coarse texture, and, like some other rocks in this collection, might be equally well named gabbro on petrographical grounds. It closely resembles some of the gabbros of Carrock Fell in Cumberland, or the coarsest portion of the Whin Sill of Teesdale. The augite and felspar are very evident, but the quartz is visible only here and there in small spots. The specific gravity of the rock is 2·87. In a thin slice (2458) the felspar is found to be labradorite, with carlsbad and albite twinning and with strong zonary banding in polarised light, this being a constant feature in normal quartz-gabbros and quartz-dolerites. The pale-brown augite shows occasional striation and schiller-structure, parallel sometimes to the orthopinacoid (diallage-structure), sometimes to the basal plane (salite-structure). Needles of apatite and irregular grains of black iron-ore occur as accessories; and there is occasionally a flake of dark biotite intergrown with a fibrous light-green hornblende, which in places has been formed at the expense of the augite. Quartz is fairly abundant, partly in interstitial grains, but chiefly in interstitial patches of micropegmatite. The felspathic element of the latter is probably orthoclase, but is so turbid as to be almost opaque.'

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, pp. 111–112.

The analysed rock (24355), from the north side of Glen Dubh one-eighth of a mile W.N.W. of 386 feet O.D., is identical with the rock described above. The only point that needs to be added to Dr. Harker's description is that the iron-ore is a beautiful skeletal form of ilmenite which is intergrown with, or grown through, the pyroxenes. The Mull rock which is most closely comparable with the Glen Dubh quartz-gabbro is the lower basic portion of the differentiated ring dyke of Glen More.[1] The labradorite felspars of the Arran rock show the same, narrow, ragged, anastomosing veins of albite as are described in the Mull rock.

Olivine-gabbro, and a type rich in iron-ore, are known to occur on the south side of Glen Dubh Water, near the right-angle bend at the head of the corrie, but these rocks are not represented in the Survey collection.

A chemical analysis of the quartz-gabbro of Glen Dubh is set out in Table IV., col. 8, and is there compared with two quartz-gabbros from the Glen More ring dyke of Mull.

TABLE IV

	8.	L.	M.
SiO_2	52·43	51·32	50·04
Al_2O_3	13·50	13·96	13·32
Fe_2O_3	4·93	2·48	4·71
FeO	7·00	7·10	8·07
MgO	4·61	5·78	5·01
CaO	8·25	11·51	10·02
Na_2O	3·27	3·50	3·28
K_2O	1·08	1·16	1·08
$H_2O>105°$	1·64	1·27	1·45
$H_2O<105°$	·28	·36	·27
TiO_2	1·91	·98	2·56
P_2O_5	·21	·24	·28
MnO	·20	·34	·33
CO_2	·08	·09	·08
FeS_2	·44	nt. fd.	nt. fd.
$(Ni, Co)O$	—	nt. fd.	nt. fd.
BaO	·96	nt. fd.	nt. fd.
Li_2O	·00	nt. fd.	tr.
Cr_2O_3	·02	—	—
ZrO_2	·00	—	—
	99·91	100·09	100·50

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[1] *Mull Memoir*, 1924, pp. 325–326, and Fig. 56A. This drawing might well represent the Arran rock, with the exception that in the latter, the acid residuum is not so fine grained, and there is more quartz present.

8. (24355. Lab. No. 819). Quartz-gabbro, north side of Glen Dubh, one-eighth of a mile W.N.W. of 386 feet O.D., Arran. *Anal.* B. E. Dixon.

L. (18462. Lab. No. 441). Quartz-gabbro of the Glen More ring dyke, half a mile S.S.E. of cairn on Cruach Choireadail, Mull. *Anal.* E. G. Radley. Quoted from the *Mull Memoir*, 1924, p. 29.

M. (18455. Lab. No. 437). Quartz-gabbro, rather more than half a mile W.N.W. of Corra-bheinn, Mull. Part of the Glen More ring dyke. *Anal.* E. G. Radley. Quoted from the *Mull Memoir*, 1924, p. 29.

Inspection of the three analyses reveals very close similarity in every respect save one. The lime in the Mull analyses is distinctly higher than in that of the Arran rock. As shown by the calculation of the norms this greater richness in lime is due to a larger amount of pyroxene in the Mull types, than to the presence of more calcic plagioclase. A tabular comparison of the three rocks is given below :—

	% Salic Constituents.	% Quartz.	% Pyroxenes.	% Ab.	% An.
Arran. Anal. 8 ..	59·8	6·7	26·5	27·8	18·6
Mull. Anal. L. ..	55·5	—	29·5	29·3	18·9
Mull. Anal. M. ..	54·1	1·6	32·3 (7·3 oliv.)	27·8	18·1

The table shows that the Arran rock is distinctly more acid than those of Mull, being richer in quartz and poorer in pyroxenes. Its mineralogical composition may be taken roughly as: quartz, 6·5; orthoclase, 6·5; plagioclase, Ab_3An_2, 46·5; pyroxenes, 26·5; iron-ores, 11; the remainder consisting of apatite, pyrite, and water. The normative plagioclase works out at Ab_3An_2, but the modal plagioclase is described in each case as acid labradorite, near Ab_1An_1. The excess of albite shown by the norm may perhaps be regarded as the measure of the albitization which the felspars have suffered, although allowance must be made for the fact that a little of the soda utilized in the norm for the computation of the amount of albite undoubtedly came from the pyroxenes, which are computed as soda-free.

The general chemical similarity of the quartz-gabbros to the quartz-dolerites and basic craignurites (*see* Table II.), may be noted. The latter group, however, is poorer in lime, but richer in potash, than the former.

Hybrids and mixture-rocks, along with diorite and quartz-diorite, are well displayed in the Glen Dubh complex. There are grounds for the belief that even the homogeneous hornblendic rocks of uncontaminated aspect, are really due to very complete mixing of granitic and gabbroid magmas, or to the complete solution of gabbro xenoliths in granite or granophyre. It also seems probable that, besides mere mixing or solution, there has been, in some cases, a selective mutual interchange of certain constituents between the gabbro and the invading granite. Furthermore, on its eastern margin the gabbro has been modified by the incorporation of

Old Red Sandstone material, for the most part a fine-grained, felspathic sandstone, producing results approximately similar in kind and degree to admixture with granite. The Survey material, however, is insufficient for the complete petrographic demonstration of these views, which are based on the study of the collection of the Geological Department of the University of Glasgow.

Amongst the crags on the north side of Glen Dubh material can be gathered showing the isolation and gradual dissolution of gabbro xenoliths within a granitic magma, and the production of hornblende and biotite of identical characters with the minerals of the 'normal' diorites and quartz-diorites which are obtained from the north side of the complex in positions remote from any occurrence of gabbro. The grain-size at the same time becomes finer. Dr. A. Harker's account [1] of these extremely variable rocks cannot be bettered, and is subjoined; the description includes rocks obtained from Glen Dubh and also from other localities.

'The ring of plutonic rocks surrounding the volcanic vent consists in part of granite, but in part of more basic rocks which have been termed quartz-diorite, diorite, and gabbro. The granite itself shows by its mineralogical constitution a certain range of variety in chemical composition, the most obvious difference being in the amount of the ferro-magnesian minerals. The increasing amount of hornblende observed in a series of specimens, with other differences developed concurrently, corresponds presumably with the transition noted in the field between normal granite and the type styled *quartz-diorite*. This latter was first described by Zirkel,[2] whose account is as follows:—" . . . A fine-grained aggregate of white felspar and greenish-black hornblende, which, in spite of the smallness of the individual crystals, stand out clearly from one another, and quartz, which is first seen in the thin slice; plagioclase preponderates, but, as is common in similar rocks, there is some orthoclase present; green epidote borders the hornblende in places; the quartz is very rich in fluid inclusions; except magnetite and apatite needles, often of surprising slenderness with great length (*e.g.*, a needle 0·9 mm. long and only 0·008 mm. thick), felsitic matter is not present. Here and there occur roundish dark concretions, in which the constituents are still finer grained and the hornblende predominates strongly, like the concretions rich in dark mica in the granites. The rock is thus a beautiful quartz-diorite, the only one of its kind known from Arran, and essentially different from the augite-bearing diabasic traps."

'Some of our specimens answer very well to this description. One from Glen Dubh, north side, for example, has all the characters of a typical quartz-diorite. It has not the fine texture of Zirkel's specimen. A thin slice (7447) shows that it consists principally of plagioclase felspar and abundant idiomorphic crystals of green to greenish-brown pleochroic hornblende. The plagioclase, as in most quartz-diorites, shows strong zonary banding between crossed nicols, indicating a great difference in composition between different coats of the crystal. It can often be verified that the interior and principal part is of labradorite, while towards the margin this passes successively through andesine and oligoclase to albite. Orthoclase is quite subordinate. Quartz too is not abundant, and always occurs interstitially, either by itself or in micropegmatite. The other minerals are magnetite, in fairly plentiful crystals and grains, and apatite, here building rather stout prisms to as much as 0·01 inch (0·25 mm.) in thickness.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, pp. 105–107.

[2] *Zeits. deuts. geol. Ges.*, vol. xxiii., 1871, p. 30.

'Examining and comparing other specimens, however, we find unmistakable indications that at least part of these rocks are of abnormal nature, in that they have not originated simply by the consolidation of an ordinary rock-magma. Almost all the slices show in the interior of many of the hornblende crystals a core of colourless augite, with a highly irregular and intricate boundary between the two minerals which proves that the hornblende has replaced augite by a process which ate its way inwards into the crystal. Nevertheless it is not a case of the simple conversion of augite crystals into hornblende, which might be a secondary change, for the crystals have always the external forms proper to hornblende. We may infer that the augite was transformed (in great part) to hornblende in a still fluid magma, and the crystals thus transformed, wholly or in their external parts, continued to grow as hornblende, assuming the proper crystal forms. This suggests that the augite was of *foreign derivation*, and other peculiarities leave no doubt that this conclusion is the correct one. The proportion of the ferro-magnesian element in the rocks is variable, and this even in one specimen, a mottled or patchy appearance being often very evident to the eye. Further, there occur in some parts of the mass numerous ovoid dark patches, an inch or less in diameter, of finer texture than their matrix. These are the "concretions" of Zirkel, but they are to be interpreted as representing the debris of a basic rock almost completely digested by the originally acid magma in which they were enveloped. Thin slices show that these "*xenoliths*," or enclosed foreign fragments, have been totally reconstituted, not merely by metamorphism but by interchange of material between them and the surrounding magma. The mineralogical composition of the dark patches, and especially the occurrence of a noteworthy amount of quartz and alkali-felspars, denotes a certain degree of acidification ; and this is the case even when the patches appear quite sharply defined to the eye in a hand-specimen (7524). The richness of the matrix in ferro-magnesian elements results from the correlated process of basification of the magma, which, however, results also in great part from bodily dissolution of the xenoliths, as proved by their rounded form. The mottled rocks without defined inclusions represent a further stage of intermingling between matrix and xenoliths, and the homogeneous-looking rocks, such as the quartz-diorite first noticed, represent complete amalgamation.'

The conversion of pyroxene into greenish-brown hornblende is well shown in (24351), a specimen taken near the eastern margin of the intrusion on the floor of the Glen Dubh corrie; and in (7447) from the north side of Glen Dubh. A very much more acid type, a quartz-diorite, with abundant interstitial graphic intergrowth between quartz and alkali-felspar, and still retaining some colourless pyroxene, occurs near the head of Burn A, near the junction with Old Red Sandstone (24354).

The unmodified granophyre of the veins cutting the gabbro at the head of Burn B is represented by the slice (24372). It is a beautiful coarse granophyre, with quartz and alkali-felspar mainly in fine graphic intergrowth which often fringes idiomorphic crystals of oligoclase. A slice (24373) is cut from a medium-grained quartz-diorite free from graphic intergrowth. The dark patches seen both in the hand-specimen and in the slice are due to the irregular clotting of small anhedral hornblende crystals, which are accompanied by abundant iron-ore, and often contain cores of pyroxene. These crystals are poikilitically enclosed in the matrix of quartz and felspar. Patchy aggregates such as these appear to represent xenoliths of fine-grained gabbro in the last stages of disintegration, dissolution, and alteration. Quartz is distinctly less abundant within their boundaries than in the matrix of the rock. The slice (7446), from Tir Dubh, shows a granite vein intruding a dark rock consisting of a curious foliaceous intergrowth of anhedral green hornblende and plagioclase, which looks as if a fine-grained ophitic dolerite had undergone changes similar to those detailed above.

2. BASIC REMANIÉ MASSES INCLUDED IN THE EXPLOSION-BRECCIA, AND IN THE GRANITE

Northward from Glen Dubh a number of masses of gabbroid rocks, badly crushed and sheared, and bounded by arcuate faults, can be recognized. At the head of the central headwater of the Glen Ormidale Burn there is a broad dyke-like mass of brecciated gabbro, bounded by a crushed basalt dyke on the west, which separates it from felsite, and by a thinning tongue of felsite from the Windmill Hill intrusion on the east. The crushed gabbro is mingled with bands of hard quartzite, and is thoroughly shattered, altered, and epidotized. In the hillock south of this exposure the mass widens out, and has an outcrop 80 to 90 feet wide. Here the rock is comparatively fresh, and is a coarse gabbro consisting essentially of large plates of diallage and labradorite, with a little ilmenite (24359). The pyroxene is passing to greenish-brown amphibole along its edges. No quartz or alkali-felspar can be detected, but there are small patches of serpentine which may represent altered olivine. The rock is penetrated by thin veins of epidote. To the north of the burn the intrusion can be traced on to the hill called Torr Maol (Plate IV), where it ends before reaching the northern headwater.

Lower down the Ormidale Burn there is a mass of badly crushed and altered basic rock, which may be traced for about 300 yards across the central and southern headwaters (Plate IV).[1] It is apparently interbedded with hard white sandstone, with which it dips at 50° to the south-west. In the southern headwater the basic rock is underlain by a thin felsite intrusion which sends veins into it, and is overlain by steeply-dipping quartzite cut by at least three small masses of felsite.

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[1] This mass is mentioned in the 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 97.

The slice (24358) is a sample of this rock taken from the central headwater of the Ormidale Burn at a point 250 yards south-east of Torr Maol. The slice shows still recognizable plagioclase laths, but much of the felspar is thoroughly altered to an indeterminable turbid dust, and the ferro-magnesian minerals have broken down to serpentine and chlorite which occupy the interspaces between the felspars. The rock seems originally to have been a coarse dolerite or a fine-grained gabbro. Slice (24367) is a rock of the same type, but has been broken into angular fragments, probably representing a fault-breccia.

In the small crag on the hillside south of the String Road near the third milestone (map, Plate IV) there are exposures of crushed, sheared, and hornblendized gabbro.[1] Some types are mottled like some of those at the head of Glen Dubh; all the rocks are much shattered. At the top of the crag the rock is badly sheared, and passes into the condition of a schistose mylonite. Above the crag the gabbro disappears, and granite fragments are found in the peaty soil.

In a gully to the west the gabbro is seen overlying intensely-baked Old Red Sandstone. The stream gully (*see* Plate IV) shows a vertical junction with a felsitic contact facies of the granite. A dry gully 80 yards west of the stream gives an almost complete section through the basic mass, which is revealed as having an outcrop 150 to 200 feet wide, and intersected by veins and dykes of granophyre and aplite. Only a few fragments of gabbro are found in the next gully, and west of this point the mass disappears abruptly. It is to be interpreted as a remnant of a gabbro ring intensely shattered by arcuate faulting.

In thin section these rocks (7536, 24376) show medium-grained aggregates of idiomorphic labradorite (Ab_1An_1), and areas of strongly-pleochroic green hornblende, sometimes massive, but often fibrous (24376), which are obviously after pyroxene, as shown by their sub-ophitic relations to the felspars. The felspars are veined by clear albite (7536). The rocks are broken by numbers of planes of movement along which the amphibole has sometimes migrated. The felspar laths, while bent or broken, are, however, but little altered. The rocks were originally gabbro of the same type as that at the head of the Ormidale Burn (p. 178). G.W.T.

To the east-south-east of Glenloig, about three-quarters of a mile, there is on the east side of a little tarn a projecting mass of rather coarse black rock. It is somewhat balloon-shaped in outline, and about 250 yards in length. The rock is a hyperite composed of labradorite, diallage, and hypersthene, with some interstitial magnetite and biotite. It is surrounded by a granophyric rock, but no junction is visible.

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[1] This mass is mentioned in the 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 97.

About a quarter of a mile N.N.W. of this is Creag nam Mult, a prominent object from the road which runs through Gleann an t-Suidhe. The dark rock here forms a long and narrow outcrop with a steep face to the north, and consists of plagioclase, augite, hypersthene, and hornblende, with some interstitial quartz and micropegmatite. In the middle of this mass, which is 250 yards in length, is a gully where may be a basalt dyke. The surrounding rock is a granophyre which appears to have penetrated the hyperite in veins. There is a small detached area of a similar rock to that of Creag nam Mult 250 yards to the north-east.

About 500 yards east of Glenloig is a small section where two kinds of rock are seen—a coarse ophitic dolerite, and an augite-porphyrite, which is probably intrusive in the former rock. This section is nearly in contact with the mass of volcanic agglomerate which outcrops to the south. On the other side it is probably bounded by quartz-diorite, but no contact is visible. W.G.

One of the most interesting of the Arran rocks is that which has been designated hyperite. It is a very fresh rock of dark aspect and of moderately coarse texture, the pyroxene and felspar being clearly distinguishable in a hand-specimen. An example from three-quarters of a mile E.S.E. of Glenloig Farm (7530) gave the specific gravity 2·97. In a thin slice it is seen that by far the greater part of the pyroxene is of the rhombic kind, though some augite is also present. The rock might therefore be termed *norite.* The dominant pyroxene is of pale colour, but always decidedly pleochroic, varying from a reddish to a greenish tint. It may therefore be called bronzite. Both this and the augite show schiller structures, parallel to the pinacoidal and basal planes, but not constantly developed. It is especially noticeable that these minerals have the ophitic habit, a circumstance not common in rhombic pyroxenes. The felspars are perfectly fresh, but show, except at the border of each crystal, a dirty appearance due to very minute inclusions. Carlsbad and albite twinning are found, and the extinction-angles in symmetrically-cut sections rise to 33° or 34°, indicating labradorite but not one of the more basic varieties. Grains of black iron-ore occur, moulded on the felspar, and occasionally little scraps of biotite clinging about the iron-ore.

Specimens from Creag nam Mult show many points of resemblance with the preceding, but also certain differences, and they may be termed *quartz-hyperite* (7531, 7532). Here the accessory iron-ore is idiomorphic, and apatite becomes a noticeable constituent. Augite is abundant as well as bronzite, and there is also a considerable amount of strongly-coloured hornblende, varying from brown to green. The browner kind has proper crystal outlines, and is therefore a primary constituent of the rock, but it often contains a core of pyroxene, about which it has grown with the usual crystallographic relation. The greener hornblende, on the other hand, is evidently formed at the expense of pyroxene, usually if not always of augite, and relics of the latter mineral, of highly irregular form and with intricate boundaries, are often preserved in the interior. Not only the pyroxene, but the felspar also has a well-marked schiller structure, the arrangement following the two pinacoid planes and the basal. Finally, and especially characteristic of this rock, there are interstitial patches consisting of delicate micropegmatite.

It seems possible that the conversion of augite to hornblende in these latter rocks may be an effect of metamorphism due to the neighbouring granophyre, but this is not a necessary supposition.

A.H.

A number of basic masses occur in the region west of Glen Craigag, especially on the western side of Ard Bheinn. These have hitherto been regarded as intrusive into the breccia.[1] It is demonstrable, however, by the increasing abundance in the breccia of fragments derived from them as their boundaries are approached, that some of these masses at least are older than the breccia, and are to be regarded as on exactly the same footing as the Mesozoic and Palæozoic remanié masses which are likewise enclosed in, and have contributed material to, the breccia.

Creag an Fheidh, one-third of a mile S.S.E. of Glenloig, consists of a mass of flesh-coloured or purplish quartz-felsite, of which numerous boulders and cobbles are found in the adjacent breccia. Immediately above the felsite is a blue basalt, with an irregular but nearly horizontal base; and between the two rocks there is a soft, black, sheared, serpentinous band. The basalt is amygdaloidal in places, and contributes to the breccia in its vicinity. Its western face is highly brecciated. A little to the west of the basalt is the limestone of the Glenloig cave (p. 109); and the view that the basalt is a remanié mass derives further plausibility from this juxtaposition (*see* further, p. 182). G.W.T.

The most noteworthy of these remanié masses of basalt are found on the western and southern sides of Ard Bheinn. One forms a craggy ridge called Creagan Liatha na Cluain Monaidh between the two branches of the stream near the head of Ballymichael Glen. At its eastern end this dark basic rock is highly magnetic. The largest mass runs from the west side of Ballymichael Glen in a north-west direction to above Derenenach, and then bends towards the north-east. It is altogether one and a half miles in length and more than 200 yards wide where it is broadest, and the rock of which it is composed is similar to that last mentioned and also highly magnetic in places. At a point 550 yards E.S.E. of Derenenach the rock is a natural magnet, possessing polarity. This basic mass is certainly earlier in date than the granophyre. W.G.

For the most part this last-mentioned mass consists of a highly amygdaloidal basalt, which in places is interbedded with basaltic tuff. Just above the Rhætic exposure in Allt nan Dris, in the crag between the fork of its headwaters, the basic rock is first tuffaceous, and then passes to an amygdaloid. It has contributed unmistakable fragments to the breccia which bounds it on the western side On its eastern margin its boundary is formed by an intrusive granophyre. Examination of the basalt shows it to be a lava indistinguishable from many of the plateau-basalt types of Skye and Mull. The only thin section available (9434), from a specimen taken 550 yards E.S.E. of Derenenach, shows a comparatively coarse ophitic plexus of narrow labradorite laths with purple augite, with some iron-ores, and abundant serpentinous material suggesting original olivine. The rock is traversed by numerous anastomosing lines of crush, along which micro-brecciation has occurred with little or no mineral change, and adjacent to which the felspars are often bent and broken.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 98.

The most probable explanation of this mass is that it represents a still upstanding screen of early plateau-basalt, which is bounded by an arcuate fault on the western side, and is intruded by an acid ring dyke on the eastern side. At its north-eastern end specimens of coarse gabbro were obtained by Gunn, at a point 200 yards south-east of Creag Mhòr, or about two-thirds of a mile north-east of Derenenach. The relations of this rock to the basalt are not known, but it is likely to be intrusive. Dr. A. Harker described this rock in the following terms :[1]—

'The rocks (9435–6) are of average texture, and consist essentially of felspar, sub-ophitic light-brown augite, and irregular grains of black iron-ore. The felspar is a labradorite, with extinction-angles up to 34° in symmetrically-cut sections. The augite has a strong striation and schiller-structure parallel to the basal plane. Olivine is apparently not present.'

It is worth while noting that the above-described basic remanié masses are associated with four of the Mesozoic fragments, within a comparatively narrow, elongated, arcuate area, extending from Creag nam Mult, by Creag an Fheidh with its limestone mass, to the limestone of the 'Pigeon Cave' on Binnein na h-Uaimh, the Rhætic exposure in the Allt nan Dris, and thence round the western side of Ard Bheinn to the Lias fragment in Ballymichael Glen (Plate IV). This fact suggests arcuate faulting and fissuring parallel to and concentric with the general ring shape of the complex, and to the outer zone of explosion-breccia, along which the fragments may be supposed to have been let down and preserved. In 1925 the writer found traces of another sedimentary inclusion in the area between A' Chruach and the head of the Allt nan Calaman, where the moor is covered with numerous boulders and slabs of a whitish, round-grained sandstone. This area lies on the eastward continuation of the annular zone described above, if it be produced in that direction.

G.W.T.

3. THE EXPLOSION-BRECCIA, AND THE ASSOCIATED FELSITES AND RHYOLITES

The explosion-breccia of the Central Ring Complex consists of a heterogeneous accumulation of fragments of all sizes, ranging from masses hundreds of yards across, down to microscopic chips. The larger masses are much fissured, broken, and tumbled ; and many of the smaller fragments have suffered micro-brecciation which can be seen even in a microscopic section. The fragments are composed of the cover of Old Red Sandstone and Mesozoic rocks which originally spread over the explosive foci, and had already been domed and fissured as the result of the earliest igneous activity of the episode; fragments of the basaltic lavas which were erupted at this earliest stage; and fragments of the acid igneous rocks whose intrusion and explosive condition were the prime causes of the general fragmentation.

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 107.

The distribution of the breccia is significant. It forms a ring of very variable width, the greatest diameter of which is about one and a quarter miles. This ring (Plate IV) extends from A' Chruach, where the annular strip is half a mile wide, north-westward to Glenloig, then south-westward to near Derenenach, and thence south-eastward to Ballymichael Glen. The narrowest part of the outcrop, only 70 yards in width according to Gunn's mapping, is at a spot two-thirds of a mile south-east of the summit of Ard Bheinn. In the region about Ard Bheinn, Binnein na h-Uaimh, and Creag Dubh, there is a wide central expansion of the outcrop, where the breccia is intricately intermingled with felsite, rhyolite, and granophyre masses. It is believed that the breccia ring has been built along arcuate fissures connected with the intrusion of the outer granite ring, and that the central mass of Ard Bheinn represents the site of a volcanic focus marked by the intrusion, and possibly the extrusion, of felsitic and rhyolitic rocks. The outer ring of granite and breccia may mark the boundary of a caldera, of which the Ard Bheinn area was the somewhat asymmetrically-placed focus.

The breccia is strongly baked and hornfelsed against the later intrusions; but this will not explain the general induration of the rock in areas remote from intrusive masses. This induration, which is accompanied by extensive epidotization, is believed to be due to the transfusion of residual magmatic gases and liquids through the material. The phenomenon seems to be identical with the induration and epidotization of the Old Red Sandstone at certain points around the margin of the northern granite, at places, too, around the margin of the Central Ring Complex, and with the 'pneumatolysis' of the basaltic lavas around the calderas of Mull.[1]

Glen Craigag provides a good representative section of a part of the breccia ring. The first exposure of fragmental rock occurs about a sixth of a mile south-east of Glenloig Bridge. The contact with the granite ring is not seen. At this point the breccia has a light-coloured felspathic matrix, which includes angular fragments of green schistose grit and dark quartz-felsite. Below the gorge caused by a north-west basalt dyke the breccia contains predominant Old Red Sandstone material, both the rounded quartz and quartzite boulders detached from their matrix, and angular fragments of the conglomerate itself, being present. One of the boulders of conglomerate was 15 inches across; and near it was an angular boulder of a lavender-coloured felsitic rock with pink felspar microphenocrysts, and another of dark quartz-felsite, types which can be easily matched amongst the Kainozoic intrusives. These boulders are embedded in a dark, indurated, epidotized, quartzitic matrix.

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[1] *Mull Memoir*, 1924, p. 95.

The epidotization and induration of the breccia can be well studied above the dyke-gorge.

At the confluence of the first western tributary of Glen Craigag the breccia is mainly composed of Old Red Sandstone debris, but also contains large boulders of a fine-grained quartz-dolerite entirely similar to some of the rocks described in Chapter XII. The largest was 15 inches in diameter. At this place the breccia appears to be rudely bedded, and dips about 30° to the north-west. In the stretch of the burn opposite Creag Dubh the breccia appears to be almost devoid of Old Red Sandstone material, and is made up of basaltic, andesitic, and trachytic fragments in a scanty quartzose matrix. Near the Allt an Chruiteir the breccia contains pebbles of plateau-basalt type, along with quartz-felspar-porphyry of a typical Kainozoic habit ; and these predominate greatly over the quartzose debris presumably derived from the Old Red Sandstone.

The contact between the central granite and the breccia is seen near 635 feet O.D. The junction is almost vertical. The granite adjacent to it is greenish and fine grained; and the grain-size noticeably increases away from the contact. The junction is therefore an intrusive one. G.W.T.

The general character of the breccia is not easy to describe, for it varies much in different places. The matrix of the fragments is very often arenaceous, much like that of an ordinary coarse sandstone, and in this are found pebbles and blocks derived from various sources, igneous rocks of an acid character often predominating.

To the west of Ard Bheinn the rock may be called a brecciated conglomerate, which weathers of a brown colour, and when broken is found to have a fine grey matrix. The included fragments are quartz pebbles (generally small), quartzites, acid igneous rocks such as granite and quartz-felsite, schists, etc., all being rather angular in outline.

In Creag Shocach, to the east of Glenloig, the prominent pebbles and blocks in the rock are grits and sandstones of various kinds, more or less angular, small quartz pebbles, and quartzite pebbles generally well-rounded, like those found in the Lower Old Red conglomerates. In ascending the northern end of this crag we find many pebbles of quartz and quartzite in the coarse breccia, as well as several varieties of acid igneous rocks (but few of basic lavas) set in the ordinary grey paste. In the upper part of the crag is a quite different kind of rock, which is distinctly red in colour, with a sandy matrix containing only pebbles of quartz. All over the crag we find the nature of the rock varying. At one extreme is a breccia made up almost entirely of coarse angular or subangular fragments of sandstones, etc., of various shapes and sizes, with little or no matrix ; while at the other the rock has a fine-grained appearance externally, and on a fractured surface is seen to consist principally of a hard bluish-grey paste, imbedding small angular fragments. There is every gradation between these two extreme varieties. In no part is there any satisfactory indication of bedding. The rock weathers of the usual brown or rustybrown colour where the grey matrix exists, but does not appear to be so much altered as in some other places—as in the burn to the west for example.

In several places besides Creag Shocach the rock is a coarse conglomerate, very like the characteristic quartzite-conglomerate of the Lower Old Red formation, and there is no doubt that this formation has contributed a large part of the material which now fills the volcanic vent, though it has in most cases been broken up and mingled largely with fragments of granite, quartz-felsite, etc. It is only in a few places that the brecciated rock assumes the character of a true volcanic tuff or agglomerate made up of igneous fragments alone, and basic lavas are seldom represented in it. On the east side of the Rhætic patch in Allt nan Dris the rock has generally a fine dark-grey matrix, which in places is calcareous and becomes carious on the brown-coloured weathered surface. It contains pebbles of white quartz (small), and quartzite, always well-rounded. Rarely there are pebbles of quartz-felsite, and the schist fragments are always angular. Occasionally there are no prominent fragments, and the rock then has more the character of a fine tuff. A pebble of amygdaloidal andesite [1] was got out of the rocks about 500 yards north-east of Derenenach, and pebbles of similar character are apparently not uncommon between this locality and Creag Mhòr, where, near the edge of the granite, the rock has a chloritic and ferruginous matrix, probably from altered basic tuff-material. At the junction with intrusive basic rock 100 yards south-west of the Derenenach cave, a specimen showed a pebble of crushed and schistose grit (schist), besides the usual quartz grains, chips of andesite, etc. The breccia is much altered about three-quarters of a mile south of Glenloig farm. One of the specimens collected from near the mass of altered shale described in Chapter X has a large piece of microgranitic quartz-porphyry in a fine grey matrix much metamorphosed, with abundant new-formed biotite. To the west of this, and near the edge of the granophyre or granite, there is a vein one and a half inches wide of a fine-grained biotite-granite traversing the matrix of metamorphosed tuff, apparently of trachytic composition, with new-formed biotite; there are also fragments of metamorphosed basic lava with much biotite.

Some pebbles collected from the breccia in Allt Ruadh to the east of Derenenach are of felsite, with small isolated spherulites. Others are much decayed, but may have been andesitic in character. A fairly large collection of pebbles was made from the breccia in various localities, and they quite bear out the statement that of the igneous fragments those of a decidedly acid character predominate, though basic material may have entered more largely into the formation of the matrix.

West of Creag Mhòr the breccia comes probably directly into contact with the Lower Old Red formation, and there appears to be a break in the igneous ring.

Between Beinn Bhreac and Cnoc an Biorach a portion of the fragmental rock appears to be surrounded by the later intrusive masses, and in two places we find the breccia outside the igneous ring, or only partly included in it. One of these is at the head of Benlister Glen, to the north of Cnoc na Croise. The extent of this cannot be ascertained, as it only occurs as a small section in the burn. A dark-greenish fragmental rock, apparently of a tuffaceous character, and considerably altered, occurs quite close to the granophyre. The fragments are of quartz and of a felsitic rock, in a greenish matrix containing much hornblende (actinolitic) which has evidently been formed *in situ*. The other locality is at Cnoc an Biorach, on the south side of Ballymichael Glen, where a considerable mass of a dark, fine-grained, almost flinty rock, occurs around the Ordnance Station and to the south-west of it. Some of it is obviously fragmental, and portions which appear massive are found when examined under the microscope to consist of metamorphosed, gritty tuff, with much new biotite. Along the eastern margin of the mass a coarse breccia is visible in two places. This area appears to be bounded by granophyre and quartz-diorite, except on the south-west side, where it adjoins the rocks of the Upper Old Red Sandstone. W.G.

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[1] This rock (9426) appears to me to be comparable with the porphyritic central-basalt type of Mull. G.W.T.

Dr. A. Harker's account of the petrography of these rocks is as follows :—[1]

' A number of specimens have been examined of the volcanic agglomerate of the large vent, and of the various rocks enclosed as fragments in it (9421–9430. etc.). In general they show a *gritty-looking matrix*, stained of various colours, in which are imbedded pebbles and fragments of quartzite, vein-quartz, and other rocks. The matrix itself consists largely, and often principally, of quartz-grains, angular and subangular ; but there is also finely divided interstitial matter, which is probably to be interpreted as representing basic igneous material, too much altered for identification. Often it is largely chloritic ; in other cases there is a ferruginous or a ferruginous and calcareous cement (9423 and 9421). In addition to quartz-grains, we find sometimes little crystals and fragments of felspar (9424), grains of partially epidotized augite, and little chips of fine-textured basalt, and especially of a pyroxene-andesite.

' Among the *larger elements enclosed* in the general matrix we may remark especially fragments and rounded pebbles of quartzite and vein-quartz. Numerous other rocks are represented in fragments of all sizes. One specimen has cavities which probably represent destroyed limestone pebbles (9423). A piece of crushed and schistose grit occurs, showing films of sericitic mica, strain-shadows in the quartz, and a characteristic mylonitic structure (9424). Especially noteworthy are the fragments of igneous rocks, including andesites (9426, 9427), microgranitic quartz-porphyry (9428), and biotite- or biotite-hornblende-granite (9479–9481).

' The *metamorphism produced in the agglomerate* by the intrusions is evident in some of the specimens. One, traversed by a granite vein, is apparently a trachytic or rhyolitic tuff, in which biotite has been developed by metamorphism, while denser patches richer in biotite represent enclosed fragments of andesite (9429). Other specimens, representing the gritty tuff which is the most usual matrix of the agglomerate, show in varying degree the same development of new-formed biotite, resulting presumably from the metamorphism of the chloritic matter mentioned above (9430, 9428). In another specimen, from the edge of the mass, the chief product of metamorphism is a pale-green fibrous hornblende, often with partial radiate arrangement (6387).'

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[1] ' Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 103.

Slice (9425), from Creag Mhòr, Derenenach, south-west of 829 feet O.D., and therefore close to the large remanié basalt mass of that locality, shows fragments of altered doleritic basalt of plateau type, and debris of the same. Slice (9437) also from Creag Mhòr, is made up largely of the debris of a granophyric granite of a type common in the Central Ring Complex.

The felsites and granophyres of the central focus around Ard Bheinn and Binnein na h-Uaimh belong to both remanié blocks and to intrusive masses, which may both be broadly contemporaneous with the breccia. Felsitic breccia, with large and small angular fragments of quartz-felsite and rhyolite, is abundant on Ard Bheinn. On the other hand, near Leana Cuil, the felsite appears to vein the breccia, and has a distinctly intrusive relation to it. The large granophyre mass which crosses the Allt Bheith and the Allt Dornoch to the east of Creag Mhòr is clearly intrusive into the breccia at its northern end. G.W.T.

There remain to be described here some of the more prominent intrusive masses that, together with the breccia, form the intricate patchwork of outcrops around Ard Bheinn. Two of the largest run along the western side of the hill in parallel bands; the outer a basic rock, and the more easterly a quartz-felsite, which becomes in places coarsely porphyritic. The basic rock, the course of which has been given elsewhere, is an ophitic dolerite which, 200 yards south-east of Creag Mhòr, is replaced by gabbro (*see* p. 181).

The quartz-felsite is a light-coloured rock, somewhat coarse textured, and very different in character from most of the acid intrusions that occur between Ard Bheinn top and Glenloig. It covers a considerable area, and has in places a width of outcrop amounting to nearly 400 yards.

The dark rock at the summit of Ard Bheinn is magnetic and affects the compass strongly.[1] It appears to be a felsite with a fine-grained matrix containing whitish felspar crystals (9432). Around the summit are some bands of a white-weathering rock of a more acid character apparently. Two hundred yards S.S.E. of the summit is a grey rock banded with red (9439); it is a rhyolite with strong flow structure,[2] and may be connected with the mass of quartz-felsite that runs along the west side of the hill, but there is some doubt whether it is not a portion of a fragmental rock to which it is adjacent, as there are several fragmental masses in the intrusive rocks of this part of the hill.

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[1] The slice shows numerous small ragged masses of magnetite, which may be part cause of the magnetic effect.

[2] A typical rhyolite in thin section. The slice shows that the rock has suffered some brecciation, and is therefore probably pre-breccia. G.W.T.

Spherulitic structure occurs in a granophyric rock 300 yards north-east from the summit of Ard Bheinn. The rock forms here an oval patch about 40 yards long, the relations of which to the surrounding acid and basic rocks are not clear. The colour of it is nearly white on the weathered surface, but when broken it is seen to be a mass of spherules, each averaging half an inch in diameter.

A number of small, basic, intrusive masses occur about the Derenenach cave and around Binnein na h-Uaimh, and others are found near the Glenloig cave, but most of the intrusive rocks of the north side of the hill are of an acid character. Those which occupy the largest area, and which are most regular in their outline, are either granite or granophyre. The masses with such tortuous outlines consist generally of a fine-grained, grey felsitic rock, sometimes almost of a flinty character, minutely jointed and breaking up into splinters. It forms prominent scars at Creag Dhubh overlooking Glen Craigag. Sometimes the rock is of a darker colour and of a bluish cast.[1] Quartz in small blebs is generally present in both varieties, and most of the rock is nearly white on the weathered surface. In places the jointing in this rock is beautifully close and parallel, and very striking. Good examples occur 300 yards south of the Glenloig cave and nearly a mile S.S.E. of Glenloig, both near the junction of felsite and breccia. The latter locality is about a quarter of a mile west of the main stream of Glen Craigag.

In several places in this burn about three-quarters of a mile from Glenloig sections occur in a dark, almost black, fine-grained rock, which appears to alternate with masses of undoubted breccia. Some of the fine-grained rock is manifestly banded felsite, but here and elsewhere in this area it is almost impossible without the aid of the microscope to distinguish between the fine-grained massive rocks which are free from quartz and the highly altered matrix of the breccia where it is devoid of fragments. A pitchstone dyke pierces the breccia in a small stream two-thirds of a mile south-east of Glenloig and nearly 300 yards west from the main burn. It is dark coloured, 2 to 3 feet in width, with a hade to the south-west. It runs in a south-east direction, and perhaps has contributed in the formation of the prominent scar of felsite there. W.G.

4. THE MAIN GRANITE AND GRANOPHYRE RING, AND THE ASSOCIATED QUARTZ-DIORITES AND DIORITES

The main granite mass of the Central Ring Complex has an annular outcrop of variable width, which in general forms the periphery of the complex, and is exterior to the ring of explosion-breccia. It encircles the whole area with the exception of about a mile on the western side at Derenenach. It extends from Cnoc Dubh (*see* map, Plate IV) on the north-east, where the radial width of the annulus is greatest (about a mile), south-westward to Beinn Bhreac, and thence westward to Ballymichael Glen. It ends abruptly a quarter of a mile north of Ballymichael Glen against the breccias and younger felsites and granophyres. On the north the granite extends westward from Cnoc Dubh along the String Road by Glenloig to Tarrnacraig, and then appears to traverse southward across the outcrop of the breccia, ending at Creag Mhòr. There is a small mass of granite exposed in and near the Allt nan Dris, north of Derenenach, which may be a detached portion of the ring.

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[1] Fragments of felsite of this character are common in the breccias of Glen Craigag. G.W.T.

Another granite mass appears to form a plug which is placed almost centrally in the ring complex. It is roughly triangular in shape, about a mile in greatest width, and occupies most of the upper part of Glen Craigag (*see* p. 184).

At the external contacts, mainly against Old Red Sandstone and Triassic sediments, the granite passes into a fine-grained granophyre or even felsite, as may be well seen in the headwaters of the Glen Ormidale Burn. It may be that the large mass of felsite mapped around 1296 feet O.D., half a mile west of Windmill Hill, merely represents the chilled margin of the granite. At any rate, there is no definite boundary between it and the granite to the west. At a point nearly half a mile south-west of the top of Beinn Bhreac, the granophyre rock is beautifully spherulitic.[1]

At the middle part of its eastern boundary the granite is in contact with the gabbroid and dioritic rocks at the head of Glen Dubh (*see* p. 172).

Quartz-dioritic and dioritic rocks of entirely similar character to those of Glen Dubh occur at many places on the north-eastern and northern sides of the granite ring (*see* map, Plate IV).

G.W.T.

Quartz-diorite is a very prominent rock in Gleann an t-Suidhe and in several of the streams that join it from the south, and it occupies a good deal of the high ground between A' Chruach and Beinn Bhreac, though here the exposures are not good as the hill-tops are covered with peat. There is a good exposure in Allt nan Calaman (which is the first stream to the west of Cnoc Dubh), and in the stream at Glenloig. It was probably in one of these streams that it was noticed and described by Zirkel fifty-seven years ago (' Geologische Skizzen von der Westküste Schottlands,' 1871, p. 30). The older writers, from Jameson in 1798 [2] to Ramsay in 1841,[3] have described or included this rock under the head of syenite. It varies much in composition, in colour, and in grain. Sometimes the rock is light-grey, contains little hornblende, is very acid in character, and approaches granite in composition, as in a burn 150 yards north-east of Creag nam Mult, Gleann an t-Suidhe. The specimen described by Zirkel consisted of white felspar and greenish-black hornblende with some quartz, plagioclase and orthoclase felspars being both present. The rock often contains finer and darker patches which are richer in hornblende and appear to be more basic than the general mass of the rock. In fact, the composition of the mass seems to be constantly varying, and occasionally we find that the most basic portions of it are penetrated by acid strings and veins approaching granite in composition, which are probably derived from the same magma that produced the more basic portions. Some attempts were made to map the quartz-diorite separately from the granite and granophyre, but the attempt was given up because the rocks are so intermingled, and because it was evident that there are transitional forms between the quartz-diorite and the granophyre, and practically the rocks seem to be but different stages in the consolidation of one and the same molten mass. At all events, this is the impression one gets after examining the sections in the burns on the south side of Gleann an t-Suidhe.

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[1] ' Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 88.

[2] R. Jameson, ' An Outline of the Mineralogy of the Shetland Islands and of the Island of Arran,' p. 84.

[3] A. C. Ramsay, ' The Geology of the Island of Arran from Original Survey,' 1841.

W.G.

At the String Road bridge across the Allt nan Calaman a small quarry has been reopened for road-mending operations. It discloses a good section of the fine-grained dioritic types, varying from a light acid type, through evenly and coarsely mottled varieties, to very dark rocks. Xenoliths of the dark fine-grained variety are found within the light variety. There are also irregular mottlings of dark minerals in the light variety, passing gradually into the dark variety, and presenting evidence of thorough mixing and digestion of a basic rock within an acid magma. The acid rock is also found veining the darker rocks in sharply-bounded dykes and strings. Three-eighths of a mile from the road the stream section shows a fine junction between a white quartz-diorite or granite, and a dark diorite, with considerable enclosure of the latter. The whole section up the Allt nan Calaman shows similar phenomena. The dark diorite decidedly predominates, and the light rocks intersect it as dykes and veins of varying widths. There are very similar appearances in the quarry in Glen Craigag, a few yards from the String Road. G.W.T.

One of the most instructive sections occurs in Ballymichael Glen, rather more than half a mile above the road, where we come on to the mass of igneous rock. After passing over several yards of yellowish, crushed, felsitic rock, which probably represents a dyke, we approach a massive, dark-grey, basic-looking rock, probably a variety of diorite. Higher up this rock appears more distinctly acid, a quartz-diorite in fact; and just below the next sharp bend in the stream an irregular, yellow granitic band, 4 to 5 yards wide, which is intrusive in the diorite, crosses the burn. Some thin and still more acid veins penetrate both rocks alike. At the next bend above is a more basic-looking rock which may be a dyke, into which coarse granite intrudes, as also into granite or granophyre of the finer variety, while a thin acid vein or elvan runs along the burn in the darker and more basic rock. At the next bend to the north the rock is more decidedly an acid variety of quartz-diorite. Just above this is another intrusion of granite, and then the rock in the stream assumes a very massive character, weathering into large rounded masses, with marked joints inclined across the burn northward. This is a dark and coarse quartz-diorite. At the next bend to the north we come upon the main mass of light-yellowish acid granite, much jointed. The junction appears to be an intrusive one, the granite being the more recent rock of the two. W.G.

The field and petrographic evidence certainly suggests that the dioritic areas within the granite represent the profoundly altered and partially-digested remnants of a ring of basic rock, which may have been continuous with the masses of Glen Dubh on the east, and with those east of Glenloig. In the north-eastern part of the area the digested material seems to have transformed the granite to a more or less general quartz-diorite facies.

The interior contact of the granite against the breccia ring is unfortunately almost everywhere concealed beneath peat. The mapping, however (*see* map, Plate IV), suggests that the granite is mainly intrusive (*see*, for example, the area near Creagan Leana Muic, and west of Creag Mhòr). Furthermore, fine-grained, chilled varieties of the granitic magma are found near the contacts, as, for example, a quartz-porphyry, 60 yards north-west of summit of A' Chruach (9440). Nevertheless, in places, the breccia contains numerous boulders and pebbles of granite and granophyre indistinguishable from those of the outer ring, and it is therefore certain that some of the granite had solidified before some of the breccia had been formed.

Petrography

Dr. A. Harker's description of the granitic rocks of the Central Ring Complex is as follows :[1]—

'The *granitic rocks of the more southerly area*, forming part of the ring surrounding the volcanic vent, have many points in common with the northern granite, and especially with the finer-grained variety of that area ; but there are also points of difference which are probably significant. There is the same tendency to rude micrographic intergrowths and sometimes a frankly granophyric structure, the same abundance of quartz, and sometimes very clear indications of microperthitic intergrowth in the untwinned part of the felspar. There is, however, a somewhat larger proportion of the coloured silicates, and these embrace not only biotite, often as before of allotriomorphic habit, but also green hornblende accompanying it, or even almost excluding it. Granules of sphene come in occasionally, and in some slices there are conspicuous little crystals of zircon, in addition to the minute ones enclosed here and there in the mica. This description applies not only to the rocks intrusive in the volcanic agglomerate, but also to granite pebbles contained in the agglomerate itself and therefore derived from an older rock. It is interesting to find that here, as in the Isle of Skye, the fragments in the agglomerate preserve evidence of the existence of older plutonic rocks which are not elsewhere exposed, and that these concealed rocks were of closely the same type as those subsequently intruded in the immediate neighbourhood.'

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 105.

This description embraces rocks from Cnoc Dubh (7521), a fine-grained granophyre ; from the base of Creag nam Mult (7526), where the granite is clearly intrusive into the hypersthene-gabbro of that locality ; from north of Glenloig (7527) ; from the quarry in the Allt nan Dris, north of Derenenach (7525) ; from the small granite mass immediately east of Derenenach (9480–1) ; from Ballymichael Glen (9477) ; and from the head of Benlister Burn, on the south-east side of the ring (6388). Amongst newly-collected material which may be grouped with the above are rocks from the headwaters of Glen Ormidale (24361, 24365, 24368). A feature of the whole group, which escapes mention above because of the allusive character of the description, is the relative abundance of striated felspar. With a refractive index well below that of quartz or canada balsam, and symmetrical extinction-angles up to 15°, this felspar is nearly pure albite.

A specimen from the quarry in the Allt nan Dris, near Derenenach (24454), has been analysed by Mr. E. G. Radley, with the result set forth in Table V., 9. This analysis shows the high silica content characteristic of many Kainozoic granites of the Western Isles. It should be compared with the analyses of the northern granite (Table III., 7), and the quartz-felspar-porphyry of Bennan Head (Table VI., 11). The amount of silica is practically the same in each rock, but the two last-mentioned are richer in potash relatively to soda than that of the Allt nan Dris. This rock compares pretty closely with the granophyre of the Beinn a' Ghràig ring-dyke in Mull (Table V., N), in all respects save the silica, of which it possesses about 2 per cent. more than the Mull rock.

TABLE V

	9.	N.	10.	8.
SiO_2 ..	75·65	73.12	53·67	52·43
Al_2O_3 ..	11·89	12·44	15·47	13·50
Fe_2O_3 ..	1·19	2·09	3·24	4·93
FeO ..	1·02	1·65	7·25	7·00
MgO ..	·15	·14	4·90	4·61
CaO ..	·91	·88	8·28	8·25
Na_2O ..	3·44	3·90	2·77	3·27
K_2O ..	4·26	4·67	·80	1·08
$H_2O > 105°$	·40	·24	·23	1·64
$H_2O < 105°$	·41	·25	1·73	·28
TiO_2 ..	·28	·39	1·28	1·91
P_2O_5 ..	·16	·09	·21	·21
MnO ..	·26	·17	·31	·20
CO_2 ..	·09	·05	·04	·08
FeS_2 ..	nt. fd.	nt. fd.	nt. fd.	·44
$(Ni,Co)O$ ..	·02	nt. fd.	·04	n. d.
BaO ..	·03	nt. fd.	·04	·06
Li_2O ..	nt. fd.	nt. fd.	nt. fd.	·00
Cr_2O_3 ..	—	—	—	·02
	100·16	100·08	100·26	99·91

9. (24454. Lab. No. 824). Granophyric granite of Central Ring Complex, quarry in Allt nan Dris, 1000 feet north of Derenenach, Arran. *Anal.* E. G. Radley.

N. (14843. Lab. No. 372). Granophyre of Beinn a' Ghràig ring-dyke, Benmore Lodge, Loch Bà, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir*, 1924, p. 20.

10. (24455. Lab. No. 825). Diorite of Central Ring Complex, quarry at bridge over Allt nan Calaman, at roadside, Gleann an t-Suidhe, Arran. *Anal.* E. G. Radley.

8. Quartz-gabbro of Glen Dubh, Arran. Repeated from Table IV., p. 174.

The norms of these two rocks supply the following mineralogical comparisons. The composition of the plagioclase is computed on the assumption that all the lime in the analyses, with the exception of trifling amounts in apatite, is in the plagioclase.

	Quartz.	Total Felspar.	Or.	Plag.	Comp. of Plag.
Granite of Central Ring Complex, Arran ..	37·4	57·4	25·0	32·4	$Ab_{10}\ An_1$
Granophyre of ring-dyke, Mull	30·5	63·3	27·8	35·5	$Ab_{13}\ An_1$

The quartz-diorites and diorites involved within the granite ring are entirely similar to those already described from Glen Dubh, and are indeed included in the scope of Dr. A. Harker's account (p. 176). There is, consequently, no need for further description here. The Survey collection includes quartz-diorites and diorites from Gleann an t-Suidhe, mainly from the Allt nan Calaman (7523–4, 24377–9, 24455); from a quarter of a mile south-west of summit of Cnoc Dubh (7522); from a burn 500 yards east-north-east of Creag nam Mult (7535); and from near Glenloig (7528, 7533, 24383). The analysed rock (24455) was selected from the darkest and most homogeneous material to be found in the Allt nan Calaman exposure. It consists of a uniform, fine-textured mixture of idiomorphic, brownish-green hornblende studded with magnetite, highly-zonal plagioclase laths ranging from labradorite to marginal oligoclase, and some interstitial quartz. A little chlorite and epidote occur as alteration products. Rarely a colourless mineral occurs very patchily in the centres of the hornblende crystals; this may be original pyroxene, but there is insufficient material for determination.

The principal feature of the chemical analysis (Table V., 10) is its extraordinarily close resemblance to the analysis of the Glen Dubh quartz-gabbro, which is repeated for comparison in Table V. The discrepancies between the two analyses are mainly in silica and alumina, which are slightly higher in the diorite; on the other hand, the alkalies are lower, although the relative proportions between soda and potash are preserved. This remarkable correspondence in chemical composition may be taken as additional evidence for the view, clearly foreshadowed by Dr. A. Harker in his account of the petrography of the rocks (p. 177), that the diorites represent portions of an original gabbro ring, which have been transformed into a hornblendic rock by immersion in granite magma ; and in places partially digested and assimilated with the production of quartz-diorite.

5. THE LATE ACID INTRUSIONS

Included in this set, which is believed to represent the latest events in the history of the Central Ring Complex, are the felsite masses in and about the head of Glen Ormidale and Windmill Hill (Muileann Gaoithe), and immediately east of Derenenach,

The Windmill Hill intrusion forms a mass with an elliptical outcrop extended in a north-east to south-westerly direction for about three-eighths of a mile. On its north side it comes into contact with Carboniferous sediments ; on the east it ends off bluntly against the New Red Sandstone ; and on its southern flank, in the corrie at the head of Glen Ormidale, it has a steeply-dipping contact against the same formation. Its western boundary is against the elongated strip of Mesozoic sediments which extends north-eastward from the head of Glen Ormidale (*see* p. 105). The felsite is distinctly chilled against Triassic marls at this place, and the contact rock is beautifully banded and contorted. The main mass gradually thins out as it crosses the Ormidale corrie ; and it is injected into the hardened quartzitic sandstones in large and small veins. In fact, the whole face of the corrie is riddled with felsitic masses, which are often hard to distinguish from the fine-grained white quartzite. A thin section (24357), from the central headwater of the Glen Ormidale burn, 200 yards south-east of Torr Maol, shows an intimate interpenetration of quartzite by flow-banded, glassy, and felsitic veins. A specimen of the intrusion taken from the northern headwater of Glen Ormidale, north of Torr Maol (24360) shows a cryptocrystalline base, with numerous roughly-spherical masses of very fine-grained micropegmatite, in which a number of small phenocrysts of euhedral quartz and alkali-felspar (? albite) are set. The ferro-magnesian element is represented by small moss-like groupings of bluish-green chloritic matter, which resemble some forms of riebeckite and ægirine.

Little is known concerning the Derenenach felsite masses. One elongated intrusion forms the western boundary of the ring complex for about a mile north-north-west from Ballymichael Glen to Derenenach. It is much crushed, and appears to have been affected by the fault which bounds the complex on this side. Immediately east of Derenenach a small boss-like mass of felsite appears to be intrusive into the above-mentioned marginal mass, and to be later than the bounding fault (*see* map, Plate IV). These masses are not represented in the Survey collection.

The evidence for the age of these masses is as yet rather tenuous. The Windmill Hill felsite appears to abut against the granite ring with an intrusive contact in the headwaters of Glen Ormidale. They may be contemporaneous with the later felsitic intrusions of the Ard Bheinn focus.

G.W.T.

CHAPTER XV

THE KAINOZOIC IGNEOUS ROCKS (*continued*)

The Minor Acid Intrusions

In this chapter are described the very numerous dykes, sills, and other intrusive masses of acid composition in Arran exclusive of the large granite masses previously described. There are two main groups : (1) the coarse quartz-porphyries ; (2) the pitchstones and accompanying felsites. In both of these groups certain members are associated with rocks of tholeiitic type in composite intrusions. The riebeckite-orthophyre of Holy Island is also treated in this chapter. These rocks are of varying ages, but all appear to be later than the crinanite and quartz-dolerite sills. Some are certainly later than the northern granite, and may be contemporaneous with the rhyolite–felsite eruptions of the Central Ring Complex. Some of the felsites, however, are even later than this ; other masses, such as the Holy Island intrusion, appear to be later than the dyke-swarm belonging to the final stages of the volcanic episode (*see* p. 223). Some of the rocks here described, as, for example, the pitchstones, and the altered felsites known as 'claystones,' are amongst the most famous of Arran igneous types, and have been described frequently from the time of Jameson onwards. The phenomena of composite intrusions in this country were first described by Judd from Arran examples.[1]

QUARTZ-PORPHYRY, QUARTZ-FELSPAR-PORPHYRY, AND ASSOCIATED ROCKS

These are acid rocks with conspicuous phenocrysts of quartz, or quartz and felspars. They are often associated in various ways with hypersthene-basalt (or dolerite), and tholeiitic rocks, but occasionally occur alone. The largest masses are exposed on the southern and western coasts of Arran. One of the best known is that which extends from Bennan Head to Cnoc Clauchog, a distance of 3½ miles, with an average width of outcrop of half a mile. About two square miles of country are thus occupied by this intrusion. Another widespread intrusion of the same character is that of Kilpatrick, which forms a range of cliffs at Brown Head, and extends from Corriecravie to Kilpatrick Point, a distance of 2½ miles, with an average width of a mile. The area occupied is thus about 2½ square miles.

The next quartz-porphyry along the west coast is that of Drumadoon, which forms the striking columnar cliff near Drumadoon Point (Plate V, Fig. 2). This beautiful sill is closely associated with a broad dyke of the same petrographical character which, starting from the north side of Drumadoon Bay, runs north, flanks the Drumadoon sill on its eastern side, and enters the sea at Cleiteadh nan Sgarbh. What is probably the same dyke reappears on the shore three-quarters of a mile farther north at An Cumhann. The traceable length of this dyke is thus about 2 miles.

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[1] 'On Composite Dykes in Arran,' *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, pp. 536–565.

The only other large intrusion of quartz-porphyry is the great plug of Dun Dubh in the Corrygills district. This is probably associated with two dykes on the Corrygills shore. Finally, the ridge called Sgiath Bhàn, which separates Glen Dubh from Glen Ormidale, is intersected by a number of thick quartz-porphyry dykes ; and one or two dykes of the same nature are to be found in the Allt Dhepin, in Benlister Glen, and in Monamore Glen.

The Bennan Intrusion (Figs. 24, 25)

This mass has been described by many of the earlier writers on Arran geology. The first modern description, however, was given in 1895 by Corstorphine,[1] who dealt fully with the field and petrographical characters of the intrusion, and recognized the xenocrystic nature of the quartz and felspar crystals enclosed in the associated 'diabase.' The Bennan intrusion is closely similar to the great composite sill of the south of Bute, which was described in the Memoir on North Arran, etc. (1903),[2] and was later more fully dealt with by Dr. W. R. Smellie.[3] The Bennan intrusion has recently been re-examined by Mr. J. V. Harrison, mainly from a petrographical point of view.[4]

The Bennan mass is a composite intrusion consisting of quartz-felspar-porphyry and hypersthene-dolerite. It is best exposed at its south-eastern end, where its outcrop impinges on the coast at Bennan Head, and forms that striking headland. Not much is known of the northern part of the intrusion, which is largely covered by drift, although the Kilmory Water cuts a trench through it. A broad area of quartz-porphyry extends from Cnoc Clauchog, 3 miles N.N.E. of Lagg, south-south-eastwards to Bennan Head. In its northern part the outcrop reaches 1½ miles in width, but towards Bennan it narrows down to half a mile. At Bennan Head the outcrop makes a sharp, hook-shaped bend, and extends three-quarters of a mile to the north with a continually narrowing outcrop, until it just reaches the main road a third of a mile west of Levencorroch. The best sections are to be seen in the small quarries near the road, along the outcrop to Bennan Head, and in the Struey Water which dissects the intrusion along the median line of the above-mentioned sharp bend.

At its termination the Bennan mass stands out as a steepsided, dyke-like ridge from 80 to 100 yards across. A wall-like junction against the sediments is clearly seen along the road leading to East Bennan farm. The intrusion consists of an interior mass of quartz-porphyry, flanked on east and west sides by basalt and dolerite. The quarry a third of a mile west of Levencorroch affords a partial section across the intrusion. Most of the exposure is in quartz-porphyry; but to the west side of the quarry there is a gradual though rapid passage to basalt by the enclosure of increasing numbers of basalt fragments, and the darkening of the quartz-porphyry by the absorption of basaltic material, until the acid rock is reduced to mere veins and strings in the predominant basaltic rock. In the smaller quarry nearer the road there is a similar transition to hybrid rocks, but this time in an easterly direction. Although the evidence is clear that the quartz-porphyry is the later member of the composite intrusion the basalt nevertheless contains a large number of quartz and alkali-felspar xenocrysts which it must have acquired before injection.

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[1] 'Ueber der Massengesteine der südlichen Theiles der Insel Arran,' *Tschermaks Min. u. Petr. Mitth.*, vol. xiv., 1895, pp. 443–470.

[2] pp. 98–99, 115–116.

[3] 'The Tertiary Composite Sill of South Bute,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 121–139.

[4] 'The Geology of a Composite Intrusion at Bennan, South Arran,' *ibid.*, vol. xvii., part ii., 1925, pp. 173–180.

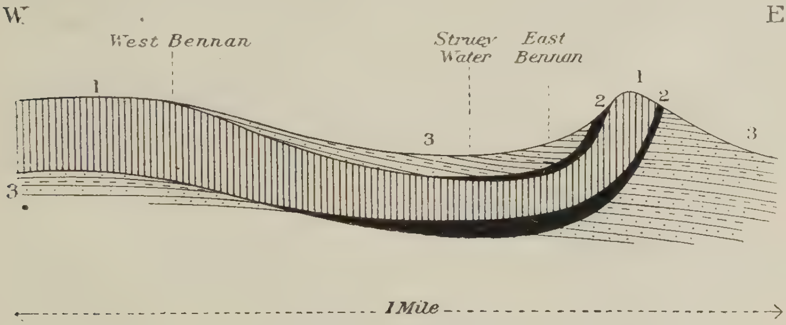


FIG. 24.—*Section across the Bennan composite sill.*

1. *Quartz-porphyry*; 2. *Basalt and dolerite*;
3. *Triassic sediments (sandstones and marls).*

Both the flanking sheets of basalt can be traced south-westwards to the Struey Water. In the intervening area the intrusion forms a range of columnar cliffs fronting the sea. The adjacent Triassic marls and sandstones to the east are practically horizontal, and strike directly against the steeply-inclined lower edge of the intrusion (Fig. 24). Several intercalations or floats of sedimentary rocks are to be seen in the lower basaltic sheet. Two of these floats are exposed in the Black Cave, on the shore just east of the Struey waterfall, where a cake of sediments 10 feet by 3 feet in cross-section can be examined.

The exposures in the Struey Water are as shown in the section, Fig. 25. The lower part of the sill consists of coarse basalt or dolerite, forming the cliff over which the Struey Water falls on to the shore. The lower contact is not actually seen, although the occurrence of sedimentary intercalations and fine-grained basalt are indications of its proximity. To judge from observations by Gunn, as recorded on his field-map, the contact plunges steeply through the sediments. The dolerite, which is here coarse grained, is exposed for 150 yards upstream from the waterfall, when, at a sharp turn, the proximity of the central quartz-porphyry is shown by the occurrence of a thick mass consisting of dolerite fragments in a matrix of quartz-porphyry darkened by assimilation. This gives place to pure quartz-porphyry higher up. The upper sheet of basalt, with a fairly steep inclination, appears near the Cairn, a third of a mile from the mouth of the burn.

While there is an apparent thickening of the lower dolerite sheet in the Struey Water, it nevertheless fades out in the cliff a quarter of a mile to the west. Similarly the upper basalt sheet cannot be traced farther than about 200 yards west of the Struey Water. The quartz-porphyry, however, continues to the north-west, and as the inclination of the mass tends to flatten out into parallelism with the adjacent strata, the outcrop becomes wider.

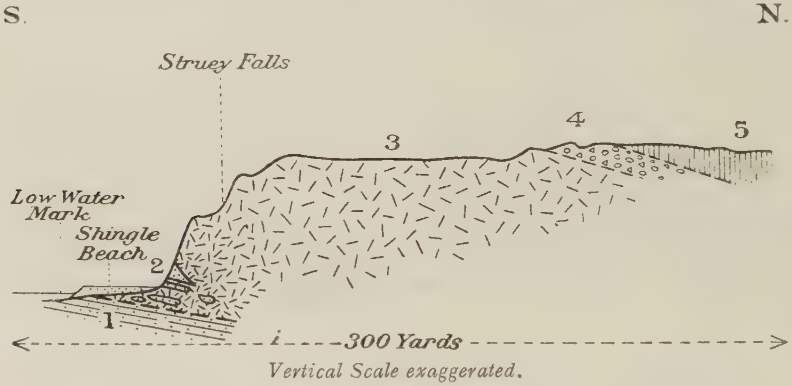


FIG. 25.—*Section along the Struey Water at Bennan Head.*

1. *Triassic sediments ;* 2. *Fine-grained basaltic contact rocks, with large enclosures of sediments, passing up into* 3. *Coarse hypersthene dolerite (increasing size of ornament denotes increasing grain-size) ;* 4. *Zone of coarse xenolithic rock with dolerite fragments in quartz-porphyry matrix ;* 5. *Quartz-porphyry.*

The solid rocks in that part of the outcrop which is intersected by the Kilmory Water are much obscured by thick drift, but two masses of basaltic rock are involved with the quartz-porphyry near Aucheleffan (*see* One-inch Geological Map, Arran, 1910).

The general relation of the intrusion to the sediments in the Bennan area is that shown in the section, Fig. 24. The steepening on the eastern margin may possibly be due to faulting, the intrusion having ascended along a fault plane. This interpretation is suggested by Gunn on his field-map (Buteshire, Arran, Sheet 259 N.E.).

The field and petrographic resemblances between the Bennan intrusion and that described by Dr. W. R. Smellie from south Bute are striking, although the Bute intrusion is a quintuple composite sill, and the Bennan mass, so far as known, only triple. Just as at Bennan, there is indubitable evidence in Bute that the acid rock is the later injection ; nevertheless the early basaltic member contains xenocrysts of quartz and felspar which could only have been derived from a magma identical with that of the quartz-porphyry. Dr. Smellie concluded on good evidence that the enclosure of xenocrysts, and the partial acidification of the dolerite, took place immediately before intrusion. It is difficult to imagine the mechanism by which the intrusion of these puzzling composite sills was effected, and the whole question needs much further investigation.

The Kilpatrick Intrusion

The name ' Kilpatrick intrusion ' is applied to the wide stretch of quartz-porphyry which occupies the area between Corriecravie and Kilpatrick Point, and forms the cliffs of Brown Head at the south-western corner of Arran. The dimensions of this mass are given on p. 195. As mapped by Gunn (*see* One-inch Geological Map, Arran, 1910) a central band of felsite, running south-east from Kilpatrick to near Cnocan Doun, is injected into the mass ; and the intrusion is flanked on its eastern margin by another mass of felsite, which forms The Torr (728 feet O.D.), and stretches away to the N.N.W. as a separate intrusion for 2 miles, terminating at North Feorline, Blackwaterfoot.

The Kilpatrick quartz-porphyry is well exposed at many places, particularly along the shore at Brown Head ; but its contacts with the sediments are hardly seen at all, and it is therefore difficult to determine the real form of the mass. A re-entrant in the base of the quartz-porphyry in a gully near the 22nd milestone, half a mile north-west of Corriecravie, shows an exposure of coarse white sandstone with pebbly bands, which dips 70°–80° to the S.S.E. The section also shows fault-breccia dipping in the same direction. The base of the quartz-porphyry appears to cut across the edges of these upturned and dislocated strata, but the actual junction is not visible.

No junction is visible at the north end of the mass. The quartz-porphyry is exposed along the shore to Kilpatrick Point, and is there buried beneath sand and shingle. Here the intrusion must be some hundreds of feet thick, judging from the height to which it rises. In the raised-beach cliff near the caves (Preaching Cave—six-inch quarter-sheet, Bute 253 S.E.) the igneous rock shows well-marked bedding-joints dipping west at 20°, and an attempt at quarrying the massive blocks has been made at this spot.

There is no sign of any basalt or dolerite associated with the Kilpatrick quartz-porphyry.

The Drumadoon Intrusions

A well-known mass of quartz-porphyry forms the striking columnar cliff at Drumadoon Point (Plate V, Fig. 2). It is a composite sill, consisting of a central mass of quartz-porphyry approaching 100 feet in thickness, with a thin sheet of basalt at both top and bottom. The lower basalt sheet is best seen at the foot of the cliff, where it attains a maximum thickness of about 4 feet, but thins to 2½ feet towards the south end of the cliff. The very thin upper sheet of basalt can be identified by fragments on the summit of The Doon, but it is best seen on the shore at Drumadoon Point. The basalt contains xenocrysts of quartz and felspar, and is identical with the similarly-occurring rock of Bennan Head. Near Drumadoon Point the sill seems to plunge eastward through the strata at angles varying from 40° to 20°. The mass at Drumadoon Point is either injected on a lower horizon than that which appears in the columnar cliff, or has been thrown down to the south along an east–west fault line. The two masses are displaced along an east–west line about a quarter of a mile N.N.E. of Drumadoon Point, and are at different levels. It is perhaps significant in this connection that many east–west dykes cut the quartz-porphyry in this locality.

About 300 yards east of Drumadoon Point a thick dyke of quartz-porphyry projects southward into the sea. This dyke can be traced to the north, and passes immediately to the eastward of the Drumadoon sill, of which it is possibly the feeder. It crosses The Doon, where it is obscurely involved with basalt. It is again seen half a mile north of The Doon at Cleiteadh nan Sgarbh, where it runs in a N.N.W. direction out to sea. At a point on the shore 150 yards south of Cleiteadh nan Sgarbh the section is that given in Fig. 26. The quartz-porphyry is 51 feet thick, and is flanked by at least 2 feet of basalt on its western edge, and also on its eastern edge. A thin dyke-like mass of basalt 6 to 9 inches in thickness is seen about 3 feet inwards from the eastern edge. Approaching the basalt on both sides the quartz-porphyry becomes much darker, and it is only possible to distinguish it from the xenocryst-bearing basalt by the greater abundance of its phenocrysts. This evidence is in favour of the priority of the basalt; and this view is confirmed by the presence on the shore of boulders of quartz-porphyry containing basaltic xenoliths. Flanking the composite dyke on its eastern side is a mass of yellow felsite at least 33 feet thick, but its eastern edge is not here seen. This mass is finely banded parallel to its western contact, and is therefore probably a later injection than the composite dyke. At Cleiteadh nan Sgarbh the felsite appears to be flanked by basalt on its eastern side.

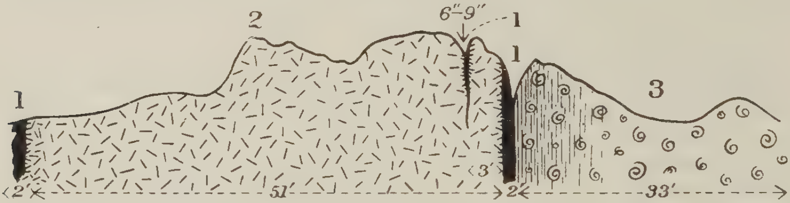
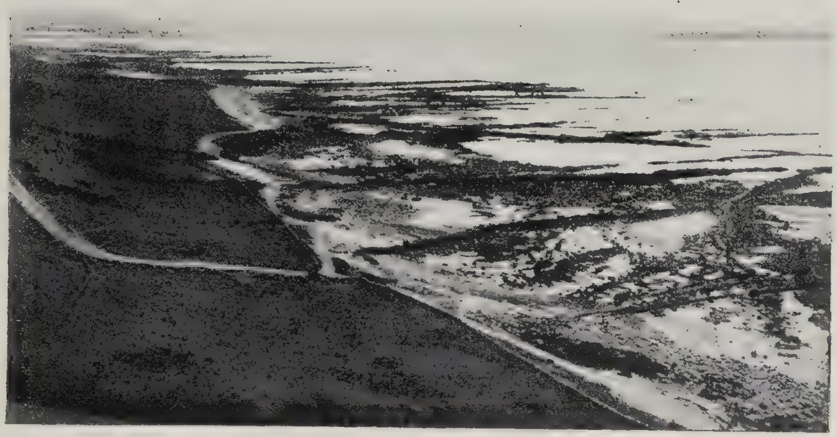


FIG. 26.—*Section across composite dyke at Cleiteadh nan Sgarbh, half a mile north of Drumadoon Point.*

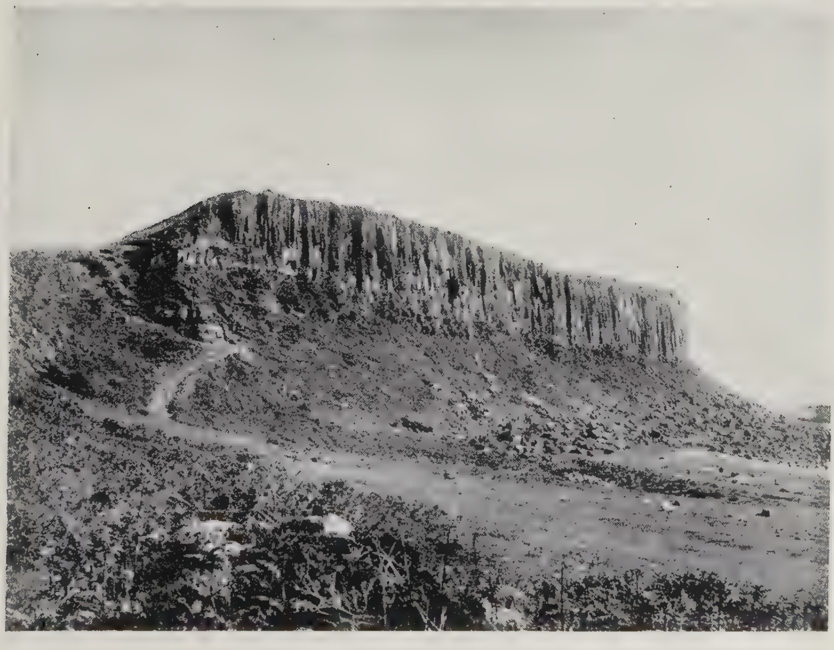
1. *Basaltic margins*; 2. *Quartz-porphyry with xenolithic contact against basalt*; 3. *Felsite, banded and sheeted at contact with basalt.*

What is almost certainly the same composite dyke reappears on

PLATE V.



(1) *Kainozoic basaltic dykes of Arran Swarm cutting Triassic sandstones. Shore between Kildonan and Bennan Head.*



(2) *Sill of columnar quartz-porphyry, with basaltic lower contact; Triassic sandstones below. Drumadoon.*

the coast three-quarters of a mile farther north at An Cumhann on the Tormore shore; but it is here running in a N.N.E. direction. The late Prof. J. W. Judd fully described this dyke in his paper on the composite dykes of Arran,[1] and gave a cross-section showing a mass of quartz-porphyry, flanked by marginal basalts 3 to 4 feet thick, and with an approximately central 'dyke' of basalt 4 feet wide. The whole mass is stated to be 90 feet wide, an estimate which agrees closely with the thickness of the dyke complex at Cleiteadh nan Sgarbh. Prof. Judd believed that the basalts were dykes intersecting the porphyry; and at least one of them shows chilled margins against the porphyry and is therefore later.

Dun Dubh

Dun Dubh is a prominent hill in the South Corrygills district, 1½ miles south-east of Brodick pier. It consists of a massive plug of quartz-porphyry extended in a W.N.W.–E.S.E. direction, and with a maximum width of 150 yards on Dun Dubh itself. To the E.S.E. it throws off a thinning tongue which crosses the Dun Fionn path, and is then lost. There is, however, a dyke of quartz-porphyry in the Corrygills cliff on the direct line of continuation of the Dun Dubh mass. Dun Dubh exhibits fine vertical columns on the north side, but these change to horizontal at the western end. No basalt has been found on Dun Dubh, but a separate exposure immediately to the north of the hill shows an obscure association of quartz-porphyry and basalt. Another dyke of quartz-porphyry 11 feet wide occurs on the Corrygills shore 200 yards south-east of the above-mentioned dyke, and due east of Dun Fionn.

Glen Ormidale and Sgiath Bhàn

On Sgiath Bhàn, the ridge that separates Glen Ormidale from Glen Dubh, there outcrops a number of large quartz-porphyry dykes, which are associated, perhaps accidentally, with basaltic members. On the eastward slope of the hill, and trending E.N.E., there is a massive dyke of quartz-porphyry at least 20 feet wide. The southern contact is not seen; but towards the northern contact (Fig. 27) the rock becomes fine grained and banded parallel to its vertical margin. At the actual junction with a strip of baked sandstone, it is practically a pitchstone. On the other side of the strip of baked sandstone there is a basalt dyke 12 feet thick. Traced upwards this dyke suddenly crosses the quartz-porphyry, and then resumes its former direction, but now on the southern margin of the acid dyke.

A second quartz-porphyry dyke is seen on the summit of the hill near its eastern end, running in a N.N.W. to S.S.E. direction. This dyke has a sharp, vertical contact with quartz-conglomerate on its western side. Near the 'B' of 'Bhàn' (Buteshire, Arran, six-inch quarter-sheet 249 N.E.) it terminates, or passes under horizontal red sandstones, but reappears about 50 yards to the west, and continues across the hill to the cliffs fronting Glen Ormidale. One hundred and fifty yards west of the above dyke a third quartz-porphyry dyke appears on the southern slopes of Sgiath Bhàn. This is 21 feet wide, and is flanked by a grey basalt dyke seen in partial exposures on its western side. This quartz-porphyry may be continuous with a dyke 15 to 20 feet wide, which cuts through a well-exposed fault in sediments and a felsite sill. The dykes of Sgiath Bhàn thus seem to have been injected into a rectangular system of fissures orientated W.S.W.–E.N.E. and N.N.W.–S.S.E.

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[1] *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, pp. 557–558, Fig. 5.

Two quartz-porphyry dykes are seen in the central headwater of Glen Ormidale Burn above 643 feet O.D. A number of other dykes which are probably to be classed here occur in Benlister Glen, Monamore Glen, and at the head of the Allt Dhepin.

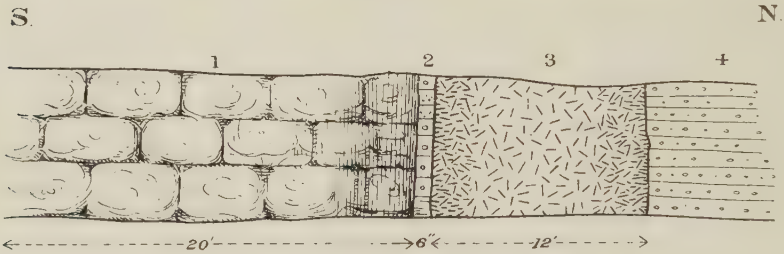

FIG. 27.—*Section across dykes on eastern slope of Sgiath Bhàn, between Glen Dubh and Glen Ormidale, Brodick.*

1. *Massive quartz-felsite becoming banded and pitchstone-like on its northern edge against* 2. *Thin strip of sandstone and conglomerate;* 3. *Basaltic dyke, chilled edges shown by size of stippling;* 4. *New Red Sandstone sediments.*

Petrography of the Quartz-Porphyries and Associated Rocks

Dr. A. Harker's general description of the quartz-porphyries of Arran is as follows:—

'The commonest type is a *quartz-porphyry rich in porphyritic elements*, which are quartz and felspar, the former usually $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter, and the latter with a length of $\frac{1}{4}$ to $\frac{1}{2}$ inch. These are often rather closely crowded in the grey groundmass, which is of fine texture, no other mineral being evident to the eye except in some examples an occasional flake of dark mica (Drumadoon, etc.). Thin slices show that the felspar is commonly sanidine, though often accompanied by some oligoclase in addition. Both quartz and felspar, but especially the former, contain abundant minute glass inclusions, and sometimes larger inclusions of the groundmass, besides having often a rounded or irregular outline indicative of magmatic corrosion. The biotite is often considerably altered, and its presence is sometimes only to be inferred from brown ferruginous patches. In no case is it abundant. Rarely a little crystal-grain of augite is seen (6396). The groundmass is always microcrystalline, sometimes having the felspar in little crystals upon which the interstitial quartz is moulded, but more usually with a granular structure and with varying degrees of fineness of texture. There is in this common type little or no approach to spherulitic or other intergrowths, though exceptionally we may see a tendency to micropegmatite in a narrow fringe on the border of a felspar crystal (6396). The quartz-porphyry rich in phenocrysts, which appears to be the general type among the large sills, is also represented among the dykes. A specimen (2455) from King's Cave is, in all respects, identical with those described above, having abundant corroded crystals of quartz, ⅛ inch in diameter, and of sanidine, often more than ¼ inch long. Another dyke-rock (6381), from Allt Dhepin, a mile south of Loch na Leirg, is essentially similar, but with smaller porphyritic crystals.'[1]

The rocks answering to the above general description in the Survey collection, are: Bennan, 6403, 6365, and 24460 (this is the analysed rock, *see* p. 204); Kilpatrick, 6396, 25079 (the felspar in this rock is chequer-albite); Drumadoon, 277 (very rich in dark red biotite and oligoclase, and distinctly more basic than the usual type), 6393–5; Drumadoon dyke, 6369; An Cumhann dyke, King's Cave, Tormore Shore, 2455; Dun Dubh, 2456, 3328 (rhyolitic flow structure in a cryptocrystalline groundmass); Allt Dhepin, one mile south of Loch na Leirg, 6381; Sgiath Bhàn and Glen Ormidale, 24364, 25043–4. In the Sgiath Bhàn and Glen Ormidale dykes the phenocrysts are fewer and smaller than in the above-described rocks, and there is abundant chlorite in the groundmass which is arranged in ragged, moss-like aggregates, recalling a common mode of occurrence of ægirine and riebeckite.

An analysis of the oligoclase crystals of the entirely similar quartz-felspar-porphyry of South Bute, by Dr. A. Scott, has been recorded by Dr. W. R. Smellie.[2] The analysis, which is set forth below, gives a calculated composition Ab_5An_1.

SiO_2	62·67		
Al_2O_3	22·48	Or	2·22
Fe_2O_3	·70	Ab	81·22
MgO	p.n.d	An	16·40
CaO	3·29	Excess Al_2O_3	·31
Na_2O	9·62	Fe_2O_3	·70
K_2O	·41	H_2O	·58
H_2O	·58		
TiO_2	nt. fd.		101·43
BaO	tr.	SiO_2 deficit (calculated)	1·68
Li_2O	tr.		
	99·75		99·75

This analysis is stated to have been made from a single crystal of the quartz-porphyry. The crystal contained inclusions of the groundmass which, no doubt, accounts for the slight discrepancies in the calculated mineral composition.

The quartz-felspar-porphyry of Bennan has been analysed by

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, pp. 109–111.

[2] 'The Tertiary Composite Sill of South Bute,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, p. 138.

Mr. E. G. Radley, with the results set forth in Table VI., 11. The poverty of this rock in FeO and MgO shows that pure, uncontaminated material was selected for analysis. In its silica percentage the rock compares closely with the granophyric granite of the Central Ring Complex (Table V., 9), and with the biotite-granite of the northern boss (Table III., 7). Nevertheless the norm calculation shows that the Bennan quartz-felspar-porphyry contains 42·4 per cent. of free quartz, as compared with 37·4 per cent. and 32·6 per cent. respectively in the other two rocks. The reason for this is found in the relative poverty of the Bennan rock in alkalies, especially soda, whereby less silica has been taken up in the formation of felspars, thus leaving a larger amount free. The Bennan rock, however, is richer in potash relatively to soda than either of the other comparable acid rocks of Arran. With the exception of its silica, the analysis closely resembles that of a hornblende-granophyre from Skye, which is tabulated for comparison (Table VI., O).

TABLE VI

	11.	O.	12.	P.	Q.	13.
SiO_2	75·22	71·98	54·83	53·97	54·11	55·79
Al_2O_3	12·22	13·13	14·10	14·65	11·65	15·97
Fe_2O_3	2·30	1·33	3·57	3·62	2·76	12·50
FeO	·22	1·64	5·87	6·32	7·02	—
MgO	·06	·56	4·88	4·49	5·30	2·22
CaO	·84	1·15	7·90	7·98	8·77	7·06
Na_2O	2·22	2·98	2·32	2·54	2·63	2·21
K_2O	4·94	4·93	1·73	1·52	1·75	1·86
$H_2O>105^\circ$	·52	1·38	1·23	·94	·81	Ign.
$H_2O<105^\circ$	·72	·39	·48	1·92	·68	2·43
TiO_2	·28	·37	·74	1·24	3·37	—
P_2O_5	·18	·19	·24	·27	·58	—
MnO	·25	·14	·37	·30	·21	—
CO_2	·03	—	1·90	·51	·05	—
FeS_2	nt. fd.	—	nt. fd.	·09	·22	—
$(Ni, Co)O$	nt. fd.	—	·03	nt. fd.	—	—
BaO	nt. fd.	tr.	nt. fd.	·04	·03	—
Li_2O	tr.	nt. fd.	tr.	tr.	nt. fd.	—
Cr_2O_3	—	—	—	—	·03	—
Cl	—	·01	—	—	—	—
S	—	—	—	—	—	·45
	100·00	100·18	100·19	100·40	99·97	100·49

11. (24460. Lab. No. 829). Quartz-felspar-porphyry, acid member of Bennan composite sill, Quarry, half a mile W.S.W. of Levencorroch, Arran. *Anal.* E. G. Radley.

O. (7064). Hornblende-granophyre, Beinn a' Chàirn, 3½ miles south by west of Broadford, Skye. *Anal.* W. Pollard. Quoted from A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 153.

12. (24457. Lab. No. 826). Hypersthene-dolerite, basic member of Bennan composite sill, shore at foot of Struey Falls, Bennan Head, Arran. *Anal.* E. G. Radley.

P. (17170. Lab. No. 432). Tholeiite, Talaidh type, basic margin of composite sill, Ruadh' a' Chromain, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir*, 1924, p. 17.

Q. (23845. Lab. No. 800). Andesitic tholeiite, 60-foot north-west dyke, a continuation of the Acklington–Hawick dyke. Lugton Water, 1000 yards south-west of Smithy, Lugton, Ayrshire. *Anal.* B. E. Dixon. Quoted from 'Summary of Progress for 1925,' *Mem. Geol. Surv.*, 1926, p. 128.

13. Augite-andesite (=Tholeiite), the exterior member of Cir Mhòr composite dyke, Arran. *Anal.* J. A. Schofield. Quoted from J. W. Judd, 'On Composite Dykes in Arran,' *Quart. Journ. Geol. Soc.*, vol. xlix, 1893, p. 545.

The basic rocks associated with the quartz-porphyries are of varying characters owing to their differing degrees of contamination with acid material; but the rocks which are comparatively free from admixture are, as the chemical analysis shows, of tholeiitic type. The rock, for example, that forms the basal contact of the Bennan sill, at the foot of the Struey waterfall (not represented in the Survey collection), is a typical tholeiite both in texture and mineral composition. The holocrystalline equivalent is a hypersthene-dolerite which is prominent in a thickening of the lower basic member of the Bennan sill at the Struey Water. This rock has been analysed (Table VI., 12). In thin section (24457) it shows irregular grains of hypersthene, clinopyroxene, and magnetite, with well-shaped labradorite laths, in a mesostasis of alkali-felspar and quartz in micropegmatitic intergrowth. The texture is fine grained allotriomorphic. The hypersthene is pleochroic from pale green to pale brown-red; its alteration near a fissure filled with calcite produces a green bastitic material, and occasionally a small flake of biotite. The slice contains one or two large xenocrysts of oligoclase, and a few rounded spots of granular pyroxene which represent completely-absorbed quartz xenocrysts.

An analysis of this rock is recorded in Table VI., 12. The main feature of this analysis is its complete accordance with analyses of tholeiitic types from the Kainozoic igneous suites of the West of Scotland, those of the Talaidh (Mull) type, of the andesitic tholeiite of Lugton (Ayrshire), and the 'augite-andesite' (tholeiite) of the composite tholeiite-pitchstone dyke of Cir Mhòr, being recorded for comparison in Table VI.

The similarities between these rocks may be further brought out by comparing their calculated mineral compositions, as in the table below:—

	Q.	or.	ab.	an.	Femic Minerals.
Hypersthene-dolerite, Bennan Head	13·8	10·0	19·4	23·1	33·7
Tholeiite, Cir Mhòr, Arran	14·6	11·1	18·4	28·4	27·5
Tholeiite (Talaidh type), Mull	10·3	8·9	21·4	23·9	35·5
Andesitic tholeiite, Lugton	10·0	10·0	22·5	15·1	42·4
Quartz-dolerite (Talaidh type), Mull	11·3	10·0	19·9	17·3	41·6
Craignurite (basic), Mull	11·9	11·7	21·5	14·2	40·8

The comparison also brings out the curious fact that while the two Arran rocks are richer in quartz and poorer in femic minerals than the other four, yet, on the other hand, they possess a more basic type of plagioclase felspar, as indicated by the ratios of total albite to anorthite.

Another slice from the Bennan mass (6376), from the base of the cliff 300 yards west of the Struey Water, contains very little hypersthene, and shows very beautiful xenocrysts of quartz surrounded by broad coronas of pyroxene, as well as one or two felspar xenocrysts with their characteristic turbidity.[1]

Slices from the base of the Drumadoon sill (25051), and from a basic member of the An Cumhann dyke (25050), are tholeiitic basalts with well-shaped microlites of labradorite, grains of colourless augite (altered to a green chloritic substance in the Drumadoon rock) and iron-ore specks. The groundmass is a dark, cryptocrystalline to glassy, substance, with which are involved small irregular areas of quartz. Both rocks contain xenocrysts of quartz and alkali-felspar. G.W.T.

PITCHSTONES, FELSITES, AND ASSOCIATED ROCKS

Dykes and sills of pitchstone, for which the Isle of Arran has long been celebrated, are pretty numerous in the island, and a good many of them occur in out of the way places in the interior which are not often visited. This glassy rock, which in some parts is called *bottle-rock* by the natives, is found of various shades of green from a light yellowish-green through various dark shades of the same colour to a black rock. Yellowish-brown and brown varieties occur, and occasionally the rock is reddish. In composition the rock varies from an almost perfectly clear glass to a coarse pitchstone porphyry, and there are spherulitic and banded varieties which remind us of similar structures in the felsites.

Both the dykes and sills of this rock are, as a rule, much more irregular or inconstant than those of the basic rocks, or of the felsites or quartz-porphyries, and we find sills changing into dykes, and *vice versa* without any apparent cause. None of the dykes or sills can be traced for very long distances, and any attempt to correlate rocks of this character at widely separated intervals is futile. One of the longest dykes (it was also the earliest to be described) is that on the Tormore shore, which can be traced for about 500 yards. The dyke or sill at the Brodick schoolhouse can be followed for nearly 350 yards into the wood to the west, but its continuation is uncertain. The sill on the Clauchland shore so often described, can be followed southwards, with breaks, for about 330 yards, when it disappears on the foreshore. The dyke or sill south of Dun Fionn is traceable for 300 yards, and it may be continuous with the lower Corrygills sill, when its total length would be about 700 yards. W.G.

The pitchstones are closely associated with compact, non-porphyritic, or microporphyritic, felsites in composite dykes; and they are occasionally found to devitrify into identical types. Some felsites appear to pass into pitchstone-like rocks on their cooling margins. Many other examples, however, occur as entirely separate dykes and sills; but their mineralogical and chemical characters, and their modes of occurrence, are so closely allied to those of the pitchstones that the two groups of rocks are most conveniently treated together. G.W.T.

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[1] A. Harker, in 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 114.

The felsite sheets, which seldom have free quartz and are not usually porphyritic in character, such as those of Holy Island on the one side of Arran and of Torr Righ Beag on the other, are probably of later date than the quartz-porphyries. In the southern part of Arran we can see the felsite dykes and sheets piercing the porphyritic rocks, and in this area we have evidence that the felsite sills are about the most recent of all the intrusive igneous rocks, for we seldom find them pierced by the ordinary basalt dykes. None have been met with in the Torr Righ Beag mass or in the felsite of Holy Island, though dykes are common in the adjacent rocks. A north-west running dyke on the South Corrygills shore does not penetrate the felsite sheet there, though it is traced for long distances on either side of it. The same felsite sheet appears two-thirds of a mile west from this place in a burn between North and South Corrygills, and here again it is clearly later in date than a basalt dyke which crosses the burn at the same spot. The larger felsite sheets in the southern part of Arran are often beautifully columnar, but examples are not common in the north, though one occurs on the north-eastern side of Holy Island. W.G.

One group of Arran pitchstones is closely associated with tholeiites in composite dykes, and thereby shows analogies with the quartz-porphyries treated in the foregoing section. Although no Arran example is known, the quartz-felspar-porphyry of South Bute does pass at one place into a thinning tongue which consists of a beautiful pitchstone-porphyry.[1] Intermediate and basic types of pitchstone (cf. leidleite and inninmorite) occur in connection with the craignurite and quartz-dolerite groups (pp. 132, 137). Hence it may be concluded that several magmatic rock types in Arran may, under suitable circumstances, give rise to pitchstone.

The field occurrences of the pitchstones and felsites will be described in order from north to south of the island.

The Northern Area

Eighteen occurrences of pitchstone are to be found within the northern granite, and in the rocks adjacent to it, that is to say, in the region north of the String Road from Brodick to Machrie Bay, and exclusive of the Glen Shurig pitchstone which occurs almost on the road. The following are some brief notes on the various occurrences in this area:—

Beinn a' Chliabhain.—A composite dyke with basic sides and porphyritic pitchstone centre occurs 50 yards north of the highest point (2217 feet), and again 300 yards to the east.

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[1] W. R. Smellie, 'The Tertiary Composite Sill of South Bute,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, p. 127.

Beinn Nuis.—A dark pitchstone dyke 6 feet wide is found about 500 yards south-east of the summit.

Beinn Tarsuinn.—A dark pitchstone is visible 150 yards south-west of the summit. There are probably other small outcrops on this hill.

The Saddle.—To the east of Cir Mhòr and nearly a quarter of a mile south-east of The Saddle is a greenish grey pitchstone, running W.N.W. Some of it is columnar.

Cir Mhòr.—Green porphyritic pitchstone forms the centre of the composite dyke on Cir Mhòr, running east and west, described by Prof. Judd.[1] The dyke is exposed in a steep gully on the eastern face of the mountain, attainable by a stiff climb from The Saddle between Glen Rosa and Glen Sannox. It consists of five members; two external margins, each about 20 inches thick, of a brown-weathering spheroidal tholeiite, which is blue on a freshly-broken surface; two interior quartz-felsites, a whitish rock with well-marked vitreous contacts against the tholeiite, each band being about 6 feet thick; and finally a central band of pitchstone about 2 feet thick, which narrows in one place to a foot.[2] The vitreous contact rock of the felsite contains small, rounded, brown inclusions which appear to be xenoliths of the weathered tholeiite. If so, a considerable interval of time must have elapsed between the intrusions of the basic and acid members of the dyke. The microscope shows that the felsite is merely a devitrified phase of the pitchstone: indeed, Judd says there is a passage between the two rocks. Measurements across the dyke about halfway up the gully show that the total width there is about 17 feet. Judd gives the minimum and maximum widths as about 12 and 30 feet respectively.

Caisteal Abhail.—On the ridge between Cir Mhòr and Caisteal Abhail a dark pitchstone dyke occurs in the cliff a little south-east of the strong spring, and a quarter of a mile south of the point marked 2735 feet on the One-inch Map.

Caisteal Abhail.—A dark columnar pitchstone occurs west of the highest point, and may be traced a considerable distance in a north-west direction by the loose fragments lying at the surface.

Another dark-coloured pitchstone dyke may be found under a crag about 100 yards north of the summit.

Creag Dhubh.—About a mile north of Caisteal Abhail a pitchstone dyke about 6 feet wide is visible for a short distance under the scars of Creag Dhubh.

Penrioch.—North-east of Penrioch and nearly half a mile E.S.E. of Auchmore or South Thundergay is a remarkable porphyritic pitchstone, only visible for about 6 yards (*see* p. 283, *under* 1928).

Dubh Loch.—On the slopes of Beinn Bharrain a quarter of a mile N.W. of the Dubh Loch is a yellowish, streaky pitchstone, 3 to 4 feet wide, which may be traced to the W.S.W. for nearly 200 yards.

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[1] 'On Composite Dykes in Arran.' *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, pp. 543–551. This account is prefaced by notices of the work of earlier observers.

[2] A good photograph of the Cir Mhòr dyke is given in J. W. Gregory and G. W. Tyrrell, 'Excursion to Arran,' *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, Plate XXVIb.

Iorsa Valley.—In a stream about one mile N.E. of the outlet of Loch Tanna there is a pitchstone dyke 3 to 4 feet wide with a course due north.

Iorsa Valley.—Near the heads of two small streams three-quarters of a mile north of Loch Nuis dykes and sills of various kinds of pitchstone crop out in at least four places.

Iorsa Valley.—About 600 yards S.S.W. of the outlet of Loch Iorsa a dark green pitchstone with a width of 7 or 8 feet is visible for about 10 yards.

Machrie Burn.—A dyke of light-green pitchstone 6 feet in width crosses this stream in a N.N.W. direction about three-quarters of a mile N.N.E. of Cnoc na Ceille. The stream here is called Allt Airidh Niall.

Auchagallon.—In the stream a quarter of a mile N.E. of the village there are two pitchstone dykes close together, and the more northerly of the two is accompanied by felsite. Both range somewhat north of east.

Auchagallon.—A small pitchstone dyke occurs in the old sea-cliff to the west of the village on the north side of a sandstone quarry.

Auchagallon.—A brown pitchstone also occurs on the shore about 80 yards south of the ferry.

The felsites in the northern area are few in number. They include three large and long dykes, and several smaller ones. The long dykes are somewhat irregular in direction but have a general north to south trend. One of them begins west of the summit of Caisteal Abhail, runs slightly west of south for half a mile, and then bends round to the S.S.E., passing between Cir Mhòr and A' Chir. Its total length is 1½ miles. A second dyke begins on Beinn Tarsuinn, where it is 150 feet thick, and runs in a direction slightly west of south in front of the great eastern cliff of Beinn Nuis. It crosses the southern foot of the final slope of Beinn Nuis at 2190 feet O.D., and is there thick and flow-banded. Another example, which may be particularized as the Glen Shurig dyke, traverses Glen Shurig along a general N.N.E. to S.S.W. course. Its trend is somewhat irregular, no doubt because it is injected, not into straight-jointed granite, but into the variable, highly-dipping beds of the Lower Old Red Sandstone. The dyke is seen in Glen Shurig, and in most of its tributaries, but the only good exposure is in the Allt an Bhrighide on the north side of the glen, where it has an outcrop at least 100 feet wide. A second felsite dyke, 40 feet wide, occurs a few yards downstream. The main dyke is again seen in the ditch by the side of the String Road near 483 feet O.D., a third of a mile west of the second milestone ; and it is likely that a felsite dyke on the ridge immediately east of Windmill Hill (Muileann Gaoithe) is its continuation. If this is so, the dyke has a total length of 1½ miles.

There are several small felsite dykes within the northern granite, of which the most important, perhaps, is that on the ridge called Stacach, about 300 yards north of the summit of Goatfell. This dyke is composed of a light-grey felsite enclosing xenoliths of a darker igneous rock (variolitic tholeiite in thin section). Small pitchstone fragments are scattered all over the outcrop, and as these also contain the basic xenoliths, it is probable that the felsite is merely a devitrified pitchstone.

The Brodick Area

There are several interesting occurrences of pitchstone in this area, most of which are olivine-bearing.

Glen Shurig.—The Glen Shurig pitchstone, fully described by Dr. A. Scott,[1] occurs as a 5-foot thick dyke in the Lower Old Red Sandstone, and is exposed in the bed of the road leading from the String Road to the most westerly house in Glen Shurig. It is a dark-green pitchstone, containing felspar phenocrysts and abundant fresh olivine (p. 230).

Brodick School.—The Schoolhouse pitchstone is exposed in the Schoolhouse garden, and in the wood to the west. It appears to be a sill injected into the steeply-dipping New Red Sandstone of that area. It also contains felspar and olivine crystals, and is often beautifully flow-banded.

Glen Cloy.—The dark basic pitchstone associated with spherulitic felsite which forms a sill in the Glen Cloy Water, has already been described with the quartz-dolerite series, with which it appears to be genetically connected (p. 137). Dr. A. Scott has given a full account of this occurrence.[2] Two other dark pitchstones, which may be called the Kilmichael pitchstones, occur in Glen Cloy. A black pitchstone, probably a sill, is exposed for 3 or 4 feet a quarter of a mile north of Glenrickard. This rock has been fully described by Dr. A. Harker.[3] It appears to be practically identical with the pitchstone of the Glen Cloy sill (*see* Scott, *op. cit.*). Dr. A. Scott has found another pitchstone in this locality, which is indifferently exposed in a small burn in the wood to the north-east of Kilmichael, about midway between the other two occurrences. This is a glossy coal-black rock with subconchoidal fracture, and resembles the other Glen Cloy pitchstones, except that it is quite free from devitrification or alteration of any sort. Scott regards the Glen Cloy pitchstones as more basic than any other Arran pitchstones, and as belonging to a group of basic glasses which occur in and around the Central Ring Complex. It is believed that this group is allied to the leidleite and inninmorite types of pitchstones, and are the glassy representatives of the quartz-dolerite–craignurite series. They are thus in all probability earlier in time than the main group of pitchstones.

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[1] *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 147–150, Plate XV.

[2] 'A Composite Sill in Glen Cloy,' *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 140–150.

[3] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, pp. 125–126.

Glen Dubh.—Three occurrences of felsite with pitchstone-like margins are believed to belong to the same group as the Glen Cloy examples. A quartz-felsite dyke, about 24 feet wide, and trending N.N.W. to S.S.E., occurs in the Glen Dubh Water about 100 yards above its confluence with the Glen Ormidale Water. This is a grey rock with numerous small angular xenoliths of variolitic tholeiite and it becomes a dark, pitchstone-like material at its western contact. An analysis of this rock has been tabulated in a previous chapter (p. 147), and is discussed in a later section (p. 235). Two hundred yards farther up the Glen Dubh Water a massive quartz-felsite sill occurs, intersecting the Permian basaltic breccia horizon (*see* Fig. 5, p. 80). At both lower and upper edges it is chilled to a banded, greenish, pitchstone-like rock, the upper contact being against the breccia, and the lower against a basalt dyke. This sill is of the same petrographic character as the above-described dyke.

Just above the second eastern tributary to the Glen Dubh Water, a quarter of a mile S.S.W. of the confluence with the Glen Ormidale Water, there is a massive felsite dyke, 30 feet broad, and trending N.N.W. to S.S.E. On its western side it appears to have a chilled edge against an 8-foot dyke of porphyritic basalt.

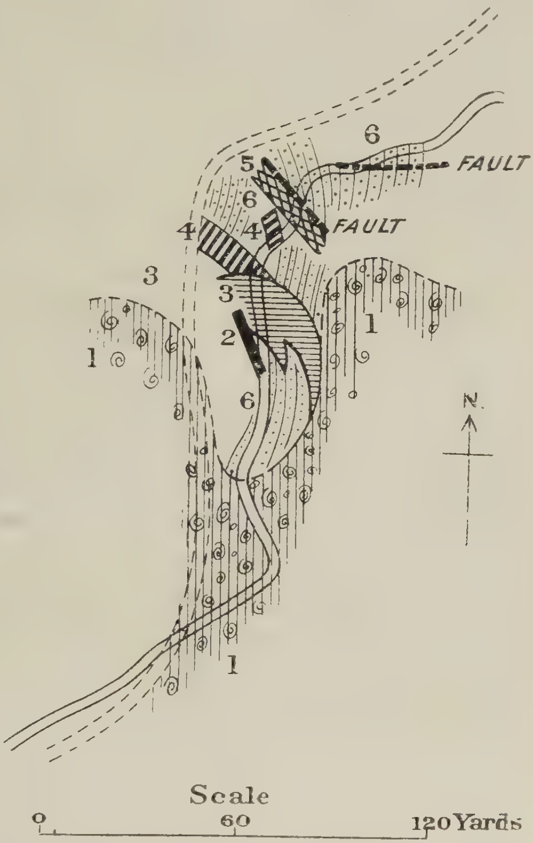

FIG. 28.—*Sketch-map of exposures in main western headwater of the Lag a' Bheith, 2 miles south-south-west of Brodick Pier.*

1. *Felsite sill ;* 2. *Basalt dyke ;* 3. *Shattery basaltic intrusion ;* 4. *Pitchstone dykes ;* 5. *Crushed basalt dyke along fault ;* 6. *Marls, cornstones, and sandstones of the Trias.*

Western Headwater of the Lag a' Bheith.—Near the head of the main western branch of the Lag a' Bheith, 2 miles S.S.W. of Brodick Pier, there are exposures of a complex of pitchstone, felsite, and basalt, which are rather hard to interpret. The complex is bounded by a fault on its north-eastern side which brings it down against Triassic marls and cornstones. Basalt adjacent to the fault is much crushed and slickensided. The main exposure of pitchstone occurs at a little fall a few yards higher up the burn. It is mostly a green type, but one band is red owing to partial devitrification. It may be a facies of the wide spread of felsite which occurs to the westward. Both this sill and the pitchstone dyke are earlier than a mass of shattery basalt which cuts across the pitchstone, and thins out beneath the felsite without penetrating it. The exposures are shown in the sketch-map (Fig. 28).

Glenloig.—In a small stream on the west side of the main valley, two-thirds of a mile south-east of Glenloig Farm, there is a dark pitchstone dyke 2 to 3 feet wide. It runs in a north-west direction and hades south-west. The dyke cuts the explosion-breccia of the Central Ring Complex.

Corrygills Area

The Corrygills area contains the best-known pitchstones of Arran, and these belong to a single, well-marked type, which is practically non-porphyritic. The locality nomenclature of these occurrences is somewhat confused, the terms Dun Fionn, Corrygills, and Clauchland, being used interchangeably for several different exposures. An attempt is made in the following notes to localize the various exposures exactly, and to give them standard names.

North Corrygills and Corrygills Shore.—This is a sill of felsite which at two places has a selvage of pitchstone. It runs from the road near North Corrygills, by a somewhat sinuous course in a general E.S.E. direction, until it reaches the Corrygills shore at a point a third of a mile south-west of the mouth of the Corrygills Burn. Its total length is therefore about one mile. Green pitchstone is seen near North Corrygills close to the road in the northern branch of the Corrygills Burn. Felsite is seen in the road bottom close by, and also in the southern branch of the burn. The rock is traceable by means of fragments across the fields to the shore, where a remarkable section is exposed. The sill dips with the strata at 35° to the S.S.W., the outcrop being about 48 feet wide. The thickness is consequently about 25 feet. Seaward it thins rapidly, and at low-water mark is only about 4 feet thick. The highly-spherulitic upper contact of the sill is irregular, and plunges steeply through the sediments. Towards its base the sill is split by an intercalation of sandstone. Beneath this it passes down into a finely-banded, fissile felsite, and at its base into a dark-grey, beautifully-spherulitic pitchstone. This is the rock which has so often been figured and described, and may perhaps be regarded as the finest spherulitic rock in Britain. The individual fibres of the spherulites stand out with perfect clearness on the dark glassy background. Its best development is in a deep ‘ pocket ’ in the sandstone underlying the sill. The pitchstone is left adhering to the sandstone slabs, and has a wrinkled appearance like ropy lava. The sill apparently breaks through the long north-west to south-east basalt dyke which is so conspicuous a feature of the Corrygills shore.[1]

South Corrygills.—A second felsite sill runs on an approximately parallel course to the first, and about a quarter of a mile south of it, through the district of South Corrygills. It is well exposed in the road at 264 feet O.D., and is there a beautiful spherulitic rock which is distinctly pitchstone-like in places. It cannot be traced any farther east from this point, but westward it runs as far as Corrygills Wood. Its length is thus approximately half a mile. At a spot 100 yards west of 278 feet O.D. on the road, Gunn found a pitchstone exposure about 25 feet in length. This is probably connected with the felsite sill.

Dun Fionn.—The term Dun Fionn pitchstone may properly be applied to two exposures on the slope above the Dun Fionn path half-way between Dun Dubh and Dun Fionn, and about 2 miles south-east of Brodick Pier. Another exposure occurs on the southern slope of Dun Fionn itself. The two above-mentioned exposures form sill-like outcrops just beneath the scarp of the Clauchland crinanite sill. The lower one shows a thickness of 20 feet, and the upper of 12 feet. No contacts are visible, and the outcrops cannot be traced more than about 50 yards in any direction when they disappear under the turf. Both sills consist of a green, platy, non-porphyritic pitchstone of the characteristic Corrygills type. Mr. John Smith records the occurrence of large detached spherulites in rabbit-burrows on the hill-slope above Dun Fionn farmhouse.[2] The exposure under Dun Fionn is of the same character, but is partially devitrified and spherulitic. It traverses the Clauchland crinanite, and can be traced westward by means of loose fragments. It is probably a continuation of the lower of the above-mentioned sills.

Clauchland Shore.—This is the green columnar pitchstone which has been so often described as the Corrygills pitchstone. It is, however, properly on the Clauchland, and not on the Corrygills, shore. It is visible near the base of the crags for 150 yards, and dips S.S.W. at 30°, nearly as the sandstone below it, but it clearly cuts the sandstone, though there is little alteration effected by it. Nearly 200 yards south of this it is visible on the foreshore for about 50 feet. The maximum thickness may be estimated at 20 feet. Mr. John Smith has figured detached microlites which have weathered out from decomposed bands at the base of the sill.[3]

Clauchlands Cottage.—On the southern slope of the Clauchland Hills a black pitchstone dyke occurs in the burn near Clauchlands

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[1] The writer is not satisfied that the felsite actually breaks through the basalt (*see* p. 221). The latter, rather, appears to plunge beneath the felsite, for baked sandstone lies across its course, and intervenes between it and the felsite. It looks as if the skin of hard-baked sandstone on the margins of the felsite had proved too difficult an obstacle for the dyke to penetrate. On the south side of the felsite the dyke certainly shows some thinning and irregularity. G.W.T.

[2] *Trans. Geol. Soc. Glasgow*, vol. x., part i., 1895, p. 166.

[3] *Trans. Geol. Soc. Glasgow*, vol. xi., part ii., 1900, p. 275.

Cottage. Its direction appears to coincide with that of the burn at the point, *i.e.* N.N.W.

Lag a' Bheith.—A thick pitchstone occurs in the Lag a' Bheith just above the point where the old Brodick–Lamlash road crosses the burn. It appears to be a sill as it passes beneath the strata of the New Red Sandstone in an obscure section on the upstream side of the exposure. Downstream it is flanked by a basalt dyke. The pitchstone is also exposed in the bed of the old road near by.

Strathwhillan.—A dark pitchstone, probably a sill, occurs near the junction of two stone dykes, about a quarter of a mile east of the Brodick and Lamlash road and 650 yards E.N.E. of the Lag a' Bheith outcrop. It runs in an E.N.E. direction, and is approximately on the continuation of the strike of the Lag a' Bheith outcrop.

Felsites in the Corrygills Area.—The felsites directly connected with pitchstones have been described above. There are, however, two other separate occurrences, which appear to belong to the same set. One, which has been quarried, appears by the side of the road to Lamlash, rather more than a mile south of Brodick pier. It is a somewhat fissile rock, fine grained, of a pale-yellow colour, and minutely spherulitic. It has been described along with other felsites (*Geol. Mag.*, vol. ix., p. 542) by Allport. In all probability this felsite is connected with the Lag a' Bheith pitchstone, and is part of the same intrusion.

A thick dyke or transgressive sill of whitish felsite occurs on the shore 250 yards north-west of Corrygills Point. Its outcrop is 100 feet wide, and it hades to the south-east at 60°. Its thickness is therefore approximately 85 feet. It can be traced through the cliff bordering the raised beach, and thence inland by means of fragments for about half a mile.

Monamore Glen and Tighvein Area

Monamore Glen.—In the Monamore Burn, near the farm of Croc, there occur three pitchstones and a felsite dyke. Beginning the section at the small runnel which enters the burn from Croc, and working westward, we first encounter a dyke of hard dark felsite, the direction of which is approximately N.N.W. to S.S.E., judging from its jointing. After a blank interval of 20 feet, a pitchstone sill occurs in sandstone which dips 5° to 10° to the west. The lower part of the sill consists of a much-jointed, bottle-green pitchstone, which is immediately overlain by a green devitrified rock. The thickness of the whole is about 30 feet. After an interval partly occupied by sandstone, a second pitchstone sill consisting of four members appears. At its base there is about 25 feet of green pitchstone, followed by 4 feet of hard, green, platy felsite, then by 9 feet of spherulitic pitchstone passing upward into a banded variety, and finally at the upper contact there is 5 feet of a banded green rock of felsitic appearance.

The third pitchstone occurs upstream at the Woollen Mill, about 150 yards south-west of the above exposures. It makes a strong bar across the stream, striking north-west to south-east. The rock consists of a brown, banded, spherulitic glass, the banding being parallel to the edge of the dyke. At the margins it becomes red and devitrified. The upstream margin plunges abruptly through the sandstone like a dyke with a steep hade ; but the downstream margin appears to overlie a ledge of sandstone in almost horizontal position, and hence is sill-like.

Pitchstones were seen by Gunn in the Allt Lagriehesk, about 300 yards S.S.W. of the Woollen Mill, and at a point on the moor 250 yards E.S.E. of Croc. A pitchstone also occurs in the wood about 100 yards south-west of Cordon, Lamlash, as part of a small felsite sill in that locality.

Near the head of the unnamed tributary which falls into the Monamore Burn, a little above the Mill Dam, at a point 600 yards S.S.W. of the seventh milestone on the Ross Road, there is a well-marked felsite sill which appears to underlie the coarse dolerite of the Monamore complex. This sill has a pitchstone-like facies at the above-defined point.

Numerous sills and dykes of felsite, beside those mentioned above, occur in the region of Monamore Glen. Some of these which intersect the Monamore complex have been previously mentioned (p. 115, and Fig. 8). Felsite dykes are seen in each of the small road-metal excavations on the Ross Road, near the eighth milestone.[1] Many of these occurrences are, no doubt, trachyfelsites or felsites belonging to the craignurite series dealt with previously ; but others may belong to the pitchstone-felsite suite.

Tighvein Area.—On the southern shore of Urie Loch a little intrusive boss of spherulitic felsite occurs, breaking through the augite-diorite of that locality. A dyke-like mass of the same character borders the loch close by (p. 134). The former rock contains serpentinous pseudomorphs after olivine, and fresh green pyroxene, which are grouped with felspars in such a way as to suggest that the rock is a devitrified pitchstone.

In the stretch of moorland between Urie Loch and Loch na Leirg there occur two pitchstone exposures which may be parts of one and the same intrusion. One of these appears on the old Lamlash–Kilmory track about half a mile south-east of Urie Loch. It trends north-west to south-east and has a thickness of 18 to 20 feet. What is apparently its continuation occurs half a mile to the south-east, in the eastern branch of a tributary of the Allt Dhepin. Only one face of this dyke is exposed, and its thickness cannot, therefore, be measured. It has a marked platy fracture parallel to its vertical edge, and is traversed by numerous thin veins of felsite up to 3 inches in width, injected roughly parallel to the walls of the dyke.[2]

Near the head of the Allt nan Clach, one of the headwaters of the Kilmory Burn, about five-eighths of a mile south-east of the summit of Tighvein, there is an exposure of pitchstone the relations of which are very obscure because it is entirely surrounded by peat. It forms a low, flat-topped knoll elongated in a W.N.W. to E.S.E. direction, and measuring 100 yards by 30 yards. It may form part of a thick dyke, or it is possibly a lenticular swelling on a sill-like mass (*see* Fig. 17).

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[1] J. W. Gregory and G. W. Tyrrell, 'Excursion to Arran,' *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, Fig. 39, p. 420.

[2] A. Scott, 'The Pitchstones of South Arran,' *Trans. Geol. Soc. Glasgow*, vol. xv., part i., 1914, p. 17.

Two pitchstone dykes occur near the head of the eastern headwater of the Allt an t-Stuie or An Sloc, the main branch of the Kilmory Burn. The exposure is distant about half a mile S.S.W. of the summit of Tighvein. The An Sloc pitchstones have been very fully described by Corstorphine.[1] They trend in a N.N.W. to S.S.E. direction. The western dyke cuts 'felsophyric quartz-porphyry,' the eastern intersects the dolerite of the Tighvein complex.

Glen Ashdale, Allt Dhepin, and Kildonan Areas

Torr an Loisgte.[2]—A composite dyke of pitchstone and felsite occurs south of Torr an Loisgte on the south side of Glen Ashdale, cutting the scarp of the Dippin crinanite in that locality. It strikes approximately N.N.W., and can be traced about 70 yards southward, although it cannot be followed on to Torr an Loisgte. The marginal parts of the dyke, each 3 feet thick, are composed of green pitchstone ; the central part, 8 feet thick, is a banded, spherulitic felsite. The junctions between the two varieties are perfectly sharp, and the intrusion must therefore be regarded as composite. The dyke hades 45° to the south-west, and appears to occupy a N.N.W. to S.S.E. line of movement.

Boulders of pitchstone are numerous in the burn which descends from Torr an Loisgte to Glen Ashdale, but no pitchstone *in situ* could be found.

Torr na Baoileig.—A pitchstone dyke is seen in the depression between Torr na Baoileig and the scarp of the Dippin crinanite sill, at a point about half a mile W.S.W. of Torr an Loisgte. In one exposure it appears to cut the Baoileig felsite (p. 131) ; in another the crinanite. A boulder of pitchstone was found halfway up the crinanite scarp. The dyke appears to run E.N.E. to W.S.W.

Cnoc Mòr.—A little north-east of Cnoc Mòr (867 feet O.D.), on the north side of Glen Ashdale, 1½ miles W.S.W. of Whiting Bay Pier, a pitchstone is exposed. It is black when fresh, slaty-blue when somewhat weathered. From the available evidence it appears to represent a dyke running W.N.W. to E.S.E., and must be from 15 to 20 feet in width.

Cnoc an Fheidh.—A N.N.W. to S.S.E. dyke of pitchstone occurs on the slope a quarter of a mile south-east of Cnoc an Fheidh (873 feet O.D.), about three-quarters of a mile N.N.W. of Loch Garbad.

Along the steeply-plunging eastern edge of the Garbad quartz-dolerite (p. 132), several of the small burns tributary to the Allt Dhepin disclose exposures of felsite which occasionally have a pitchstone-like facies. With this persistent intrusion may perhaps be correlated a felsite mass in the gorge of the Allt Dhepin, south-east of 634 feet O.D. At one point this is a dyke, but it passes rapidly into a little columnar sill which is injected at the base of the Garbad quartz-dolerite sill.

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[1] *Tschermaks. Min. u. Petr. Mitth.*, Bd. xiv., 1895, pp. 448–451.

[2] A. Scott, *op. cit. supra*, p. 22.

Numerous dykes and sills of felsite occur in this area, but it is not always easy to decide whether they belong to the quartz-dolerite–craignurite series, or to the later pitchstone-felsite suite. Many of the larger masses unquestionably belong to the former.

Cheese Hole Felsite.—The only noteworthy felsite mass which occurs in the Kildonan district, apart from those belonging to the quartz-dolerite–craignurite series, is that of Cheese Hole, a point on the shore 250 yards south-west of Dippin Head. The rock here is a grey-blue felsite which weathers a dull chalky white. The mass is about 40 feet wide, and has a nearly north to south extension of about 70 yards. It has a plunging contact on its western side dipping 30° to 40° under horizontal sandstones. A few yards farther south there is a basalt dyke 24 feet wide, which is separated from the felsite by a strip of sandstone. Followed to the north this dyke abuts against the western edge of the felsite, and follows it as though deflected by it. The felsite terminates near the base of the Dippin crinanite scarp, and not a trace of it is found above a huge block at this point. It certainly does not cut the Dippin sill. The mass thus seems to be a small boss elongated in a north to south direction.

The South-Western Area

Burican.[1]—Just above Glenrie Bridge, on the Sliddery Water, a third of a mile south of Burican, a pink banded felsite is seen, with what appears to be a faulted junction against the Triassic sediments (Fig. 29). The nearly horizontal, slabby joint-planes of the igneous rock turn up until they become almost vertical at the junction. The absence of shattering suggests that the felsite has come up along the fault.

The Burican pitchstone forms a ledge between the road and the Sliddery Water above the felsite. It slopes down towards the river, and has a visible thickness of 20 feet. It seems probable that it represents the upper part of the banded felsite.

Allt an t-Sluic, Kilpatrick.—A pitchstone sill is visible in the Allt an t-Sluic, a headwater of the westernmost tributary of the Sliddery Water. The exposure is 2 miles E.S.E. of Kilpatrick Point. About 10 feet of pitchstone is visible; it forms a ledge in the bank of the stream, in the channel of which red marly sandstone is seen.

Cnocan a' Chrannchuir, Kilpatrick.—This occurrence is in a small burn called Allt na Craoibhe, on the north-east side of Cnocan a' Chrannchuir, about 1½ miles south-east of Blackwaterfoot. It is very poorly exposed, consisting of scattered blocks of pitchstone, and a foot or two of the rock *in situ*. From the fact that baked whitish sandstone is seen near by on the same level, the exposure is adjudged to be part of a dyke.

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[1] A. Scott, *op. cit. supra*, p. 18.

Felsites of Kilpatrick.—This term is applied to the large masses of felsite which appear to cut the quartz-porphyry of Kilpatrick, and are described on p. 199. The above two pitchstones occur within short distances of the eastern edge of the larger of these masses. These rocks, in common with the similar Blackwaterfoot masses, are singularly free from later intrusions, even of the latest series of basaltic dykes, as has been emphasized by Gunn.[1] They probably belong to the pitchstone suite.

Tormore and Blackwaterfoot Area

The pitchstones of the Tormore shore have attracted the attention of geologists from Jameson onwards, and have been rendered classic by the investigations of J. W. Judd, who pointed out their close association in composite dykes with felsites and 'augite-andesites' (tholeiites).[2]

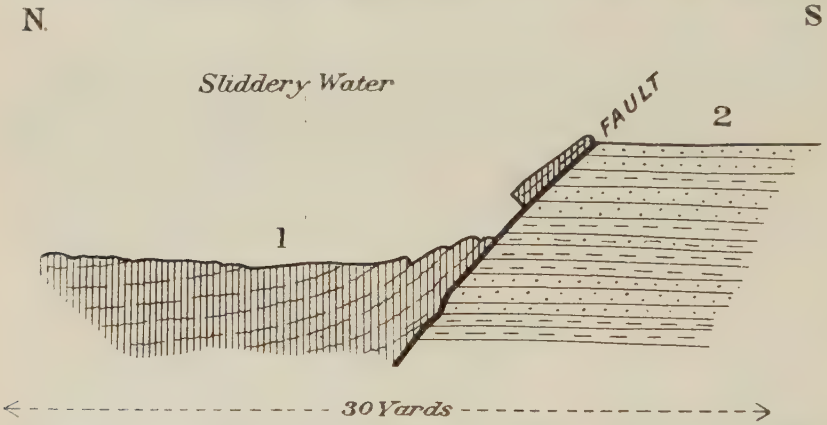

Fig. 29.—*Junction of felsite against Triassic sediments, Sliddery Water, just above Glenrie Bridge.*

1. *Felsite, with slabby jointing ;* 2. *Triassic sediments.*

Judd's No. I. Dyke (*see* sketch-map, Fig. 30).—This is the largest pitchstone intrusion on the Tormore shore. The Tormore shore is the mile-long strip of rocky coast which stretches southward from the southern side of Machrie Bay. The dyke appears at low-water mark 200 yards north of An Cumhann, and runs in a N.N.E. direction. At high-water mark, however, its direction becomes more northerly, and it ultimately passes from sight under boulders and raised-beach material. It reappears at the northern end of the section for 100 yards or so, with a northerly course. Its total

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[1] 'Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 91.

[2] 'On Composite Dykes in Arran,' *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, pp. 551–561.

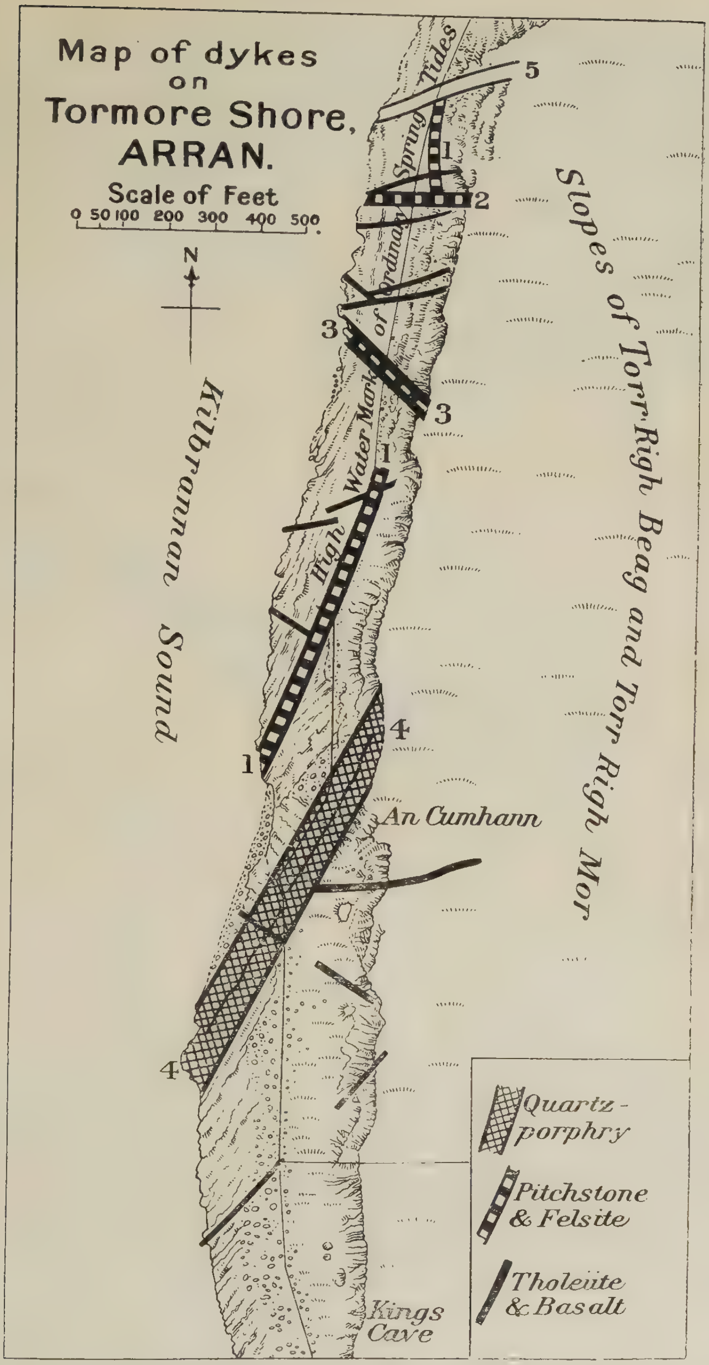

FIG. 30.—*Map of dykes on Tormore shore, based on the map by J. W. Judd* (*Quart. Journ. Geol. Soc.*, vol. xlix., 1893, p. 552).

1. *Tholeiite-pitchstone composite dyke* (*Judd's No. I. dyke*), *composite at south end, but only pitchstone at north end*; 2. *Tholeiite-pitchstone composite dyke* (*Judd's No. II. dyke*); 3. *Tholeiite-pitchstone composite dyke* (*Judd's No. III. dyke*); 4. *Composite dyke of quartz-porphyry and tholeiite* (*Judd's No. IV. dyke*), *described p.* 201; 5. *Trench with indurated edges; no dyke seen.*

exposed length is thus about 600 yards. At the northern end of the outcrop the pitchstone appears to be a vertical dyke, but towards its southern extremity, according to Judd, it hades at less than 60°. At its northern end it consists entirely of pitchstone; the southern exposures, however, show the pitchstone passing on both sides into banded, spherulitic felsite. On its eastern margin, moreover, a band of dark tholeiite intervenes between it and the adjacent sandstone.[1]

Judd's No. II. Dyke.—This dyke occurs near the north end of the Tormore section. It runs east to west, and appears to intersect the north to south dyke. Its thickness is 30 feet. Its sides are composed of tholeiite weathering in the usual spheroidal fashion, but the centre is a quartz-felsite which occupies about half the width of the dyke. A pitchstone dyke or vein, 6 inches to 2 feet in width, is found sometimes intersecting the felsite, and at other times the adjoining tholeiite.[2]

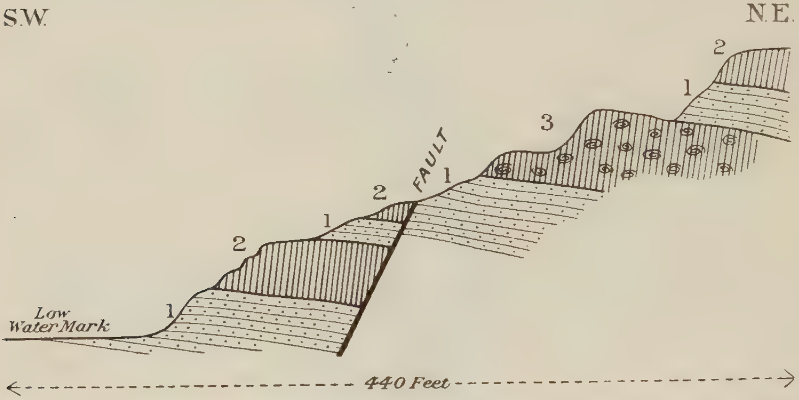

FIG. 31.—*Section across pitchstone exposures south of King's Cave, one mile north of Drumadoon.*

1. *New Red Sandstone sediments*; 2. *Pitchstone*; 3. *Spherulitic felsite.*

Judd's No. III. Dyke.—About 120 yards south of No. II., another composite dyke occurs, which trends north-west to south-east. It is from 40 to 50 feet wide, and is mainly composed of tholeiite. Somewhat asymmetrically placed there is a median band of acid rock about 5 feet thick, of which the central 2 feet consists of pitchstone, and the remainder of quartz-felsite.[3]

King's Cave.—Five separate exposures of pitchstone occur on the shore and in the cliff bounding the raised beach to the south of King's Cave, half-way between Tormore and Drumadoon. Three of these exposures are in and about a recess in the cliff made by a small stream. Just below the path on the south side of the recess there is a pitchstone sill 20 feet thick, resting on sandstone and dipping S.S.E. at 5° to 10°. A little higher up there is a small mass of shattered pitchstone. At a higher level on the opposite side of the recess there is first a sill of spherulitic felsite about 32 feet thick, and then another of banded pitchstone. Assuming that the spherulitic felsite is the same intrusion as the lowest pitchstone, an assumption for which there is petrographic warrant, the relations of the four igneous masses may be explained as in the section, Fig. 31, by means of a north-west to south-east fault running along the line of the above-mentioned gully.

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[1] Judd, *op. cit.*, Fig. 2, p. 554.
[2] Judd, *op. cit.*, Fig. 3, p. 555.
[3] Judd, *op. cit.*, Fig. 4, p. 556.

This fault-plane appears to be occupied by a felsite-pitchstone dyke, for felsite is found on the shore at the north-west end of the line, and a pitchstone dyke is recorded by Gunn at the south-east end near the head of the gully.

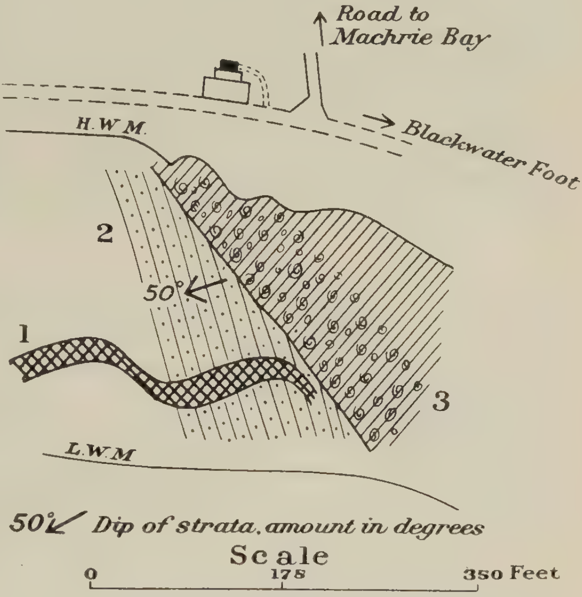

FIG. 32.—*Plan of exposures on shore, one-twelfth of a mile north-west of Blackwaterfoot.*

1. *Basalt dyke* ; 2. *Triassic sediments* ; 3. *Felsite.*

In the cliff bounding the raised beach immediately to the south of the above-mentioned exposures, another sill of pitchstone is exposed, which may represent a third horizon of this rock.

Blackwaterfoot Felsite.—A mass of columnar quartz-felsite occurs on the shore on both sides of the mouth of the Black Water. A little west of the river the sediments are steeply upturned against a vertical face of felsite; and in the raised-beach cliff near by, the joint-planes of the felsite curve steeply upwards against a junction with sediments. Although there is a slight break in the continuity of the mass at this point, there can hardly be any doubt but that the Blackwaterfoot sill is the same as that which spreads northwards almost to Machrie Bay, and forms the large area of felsite on the moor east of the Tormore shore (Torr Righ Beag and Torr Righ Mòr). This outcrop is 2 miles in length by a mile in average width, and consequently covers an area of 2 square miles. Not a single basalt dyke appears to cut this felsite mass. On the shore at Blackwaterfoot basalt dykes approach the edge of the felsite, but do not penetrate it. In the absence of an actual junction it is difficult to establish the relative ages of the two rocks. Gunn relied on the

Blackwaterfoot shore-section to demonstrate the posteriority of this group of felsites to the basalt dykes (unpublished MS. on Sheet 13); but his own 6-inch scale MS. map (Buteshire, 253 N.E.) shows the dykes, as they approach the margin of the felsite, bending into conformity with it, as though they were influenced by the proximity of the felsite, or found it difficult to penetrate. Fig. 32 also illustrates this feature.

Holy Island

The massive sill which forms the major part of Holy Island, in Lamlash Bay, was formerly regarded as a felsite, but is now known to be a trachyte or orthophyre containing riebeckite and ægirine.[1] It therefore presents certain analogies with the intrusion of Ailsa Craig, in the Firth of Clyde, 17 miles to the south of Holy Island.

The outcrop has the form of an ellipse elongated in a N.N.W. to S.S.E. direction, the axes of which are one and a half and half a mile long. A traverse across the island yields the view of its structure which is given in Fig. 33. Three main terraces and scarps are encountered, and one or two subsidiary ones. This is interpreted as meaning that the sill was emplaced in at least three pulses of injection. Its total thickness is estimated at 800 feet. It rests on sandstone, which in turn rests upon, and has been intruded by, the Kingscross crinanite sill (p. 116). While in most places the sill rests in approximately horizontal position upon the sediments, in one place on the eastern side below the summit of the island, a vertical contact of the igneous rock against sandstone is seen, and the former shows horizontal columnar structure. It may be suggested that this possibly represents one of the feeding channels of the mass.

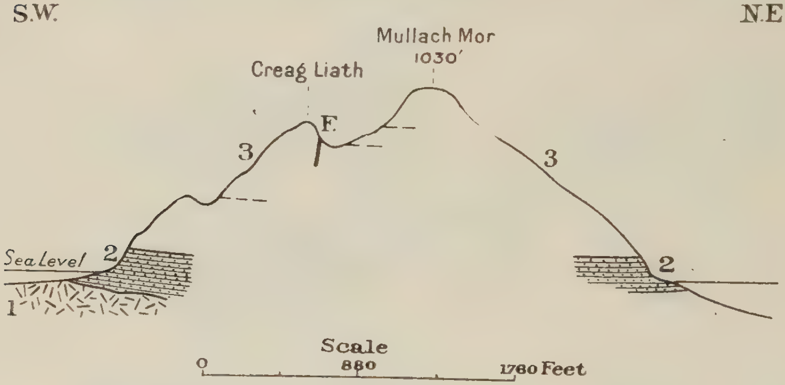

FIG. 33.—*Section across Holy Island, Lamlash Bay.*

1. *Kingscross crinanite sill;* 2. *New Red Sandstone sediments;* 3. *Riebeckite-ægirine–orthophyre sill;* F. *Zone of breccia;* ---- *Possible boundaries of supposed sheets.*

When fresh the rock is of a deep blue-grey colour, often with a greenish tinge, and with an occasional small porphyritic felspar. Notwithstanding its great thickness the rock is very fine grained throughout. It breaks and rings like a phonolite. It is intersected by closely-set vertical joints spaced on the average about half an inch apart, and running in a north-west to south-east direction. A slabby horizontal parting is also sometimes developed. The jointing seems to be potential, and to be brought out by weathering, as good thick specimens can be obtained from the interiors of blocks. In most of the crags, and especially on the western side of the island, the rock shows a massive columnar structure.

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[1] G. W. Tyrrell, 'The Petrology of Arran,' *Geol. Mag.*, 1913, pp. 305–309.

The second scarp on the west side (Creag Liath) thickens to the north, and forms a cliff at least 200 feet high. Between it and the summit (Mullach Mòr, 1030 feet O.D.) there is a rocky depression. On the western side of this valley a zone of breccia a few inches wide borders a plane of movement which hades about 70° west (Fig. 33). This plane strikes north-west to south-east, and the joint-planes and other features near it are disturbed and twisted. At the extreme northern end of the island a flattish 'felsite' feature is seen on the foreshore, and apparently represents the top of a lower sill. Red sandstone occurs immediately to the west of this exposure.

Not a single basalt dyke has been found to penetrate the Holy Island sill. On the other hand the sandstone basement is intersected by dykes which stop short at the margin of the sill. In a section on the south-east coast Gunn mapped a dyke-like north-west to south-east protrusion of 'felsite' which cuts right through a prominent basalt dyke running in nearly the same direction (Buteshire, Sheet 250 S.W.).[1] This section seems to demonstrate conclusively that the Holy Island sill is later than the north-west basalt dykes, and must therefore be one of the latest, if not the latest, igneous injection in Arran.

Notwithstanding its great thickness the Holy Island sill, in common with the other felsitic masses of Arran, has effected remarkably little alteration on the adjacent sediments. Nowhere is more than a trifling induration caused.

Petrography of the Pitchstones and Associated Rocks

It is not possible in this place to deal fully with the varied and complicated petrography of the pitchstones and their associated rocks, or to discuss in any detail the interesting petrological questions to which they give rise. The most comprehensive description extant is that by Dr. A. Harker in the Memoir on North Arran (1903), which is given below. Dr. Harker gives brief references to the work of previous investigators. Since the appearance of his description the only other modern accounts are those by Dr. A. Scott,[2] who has the distinction of being the first to point out the occurrence of olivine in the Arran pitchstones. Scott has also discussed the physical chemistry of these rocks in some detail.

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[1] The writer has not seen this section.

[2] 'The Pitchstones of South Arran,' *Trans. Geol. Soc. Glasgow,* vol. xv., part i., 1914, pp. 16–36. 'A Composite Sill in Glen Cloy, Arran,' *ibid.*, vol. xv., part ii., 1915, pp. 140–150.

G.W.T.

General Description.—Dr. A. Harker's general description of the Arran pitchstones and felsites is as follows:[1]—

Since Jameson[2] more than a hundred years ago gave descriptions, in the Wernerian fashion of the time, of several varieties, the *pitchstones* of Arran have become more widely known than any other group of rocks in the island. This is owing especially to their very beautiful microstructure, which has been made familiar to all geologists by the descriptions of Sorby,[3] Zirkel,[4] Allport,[5] Vogelsang,[6] Teall,[7] Judd,[8] Rosenbusch,[9] Corstorphine,[10] and others.

The specimens selected for examination are dark-grey or greenish-grey rocks, sometimes almost black, with the characteristic resinous lustre. They show usually only small crystals visible to the naked eye, rarely more than an eighth of an inch in length, and often rather sparingly scattered. There are, however, some conspicuously porphyritic pitchstones in the island, as described from Brodick Castle, Invercloy, and Cir Mhòr. Thin slices show under the microscope that the general body of the rock consists of a glass more or less crowded with minute crystallites. These are of two orders of magnitude, the larger easily visible, the smaller appearing with a low magnifying power only as a pigment, colouring and rendering turbid the glassy matrix. There are thus four sets of elements in the rocks—the porphyritic crystals, the larger crystallites, the smaller crystallites, and the glassy base, the last enclosing the rest and constituting the principal part of the bulk.

The porphyritic crystals embrace quartz, felspars, augite,[11] and magnetite, all with idiomorphic outlines, excepting only when they are aggregated in groups, as is frequently seen. In this case the later crystallized minerals are moulded upon the earlier, and it is seen that magnetite has preceded augite, and both have preceded the quartz and felspars. Apatite is found rather rarely. The quartz is in pyramidal crystals, sometimes rounded at the angles and often having considerable inlets of the groundmass. Both quartz and felspars also contain glass inclusions, and the glass often encloses minute crystallites.[1] The felspar is partly striated oligoclase, partly what looks like sanidine; but the latter, as remarked by Prof. Judd, has sometimes a vague appearance of very fine lamellation which is suggestive of cryptoperthite.[2] The augite is in crystals with the usual octagonal cross-section, and is of a light-green colour.

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[1] 'Geology of North Arran, etc.'. (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, pp. 120–127.

[2] 'Outline of the Mineralogy of the Shetland Islands and of the Island of Arran,' 1798, pp. 76–82.

[3] *Quart. Journ. Geol. Soc.*, vol. xiv., 1858, pp. 476, 477, Plate XVIII.

[4] *Sitz. Akad. Wiss. Wien*, vol. xlvii., 1863, pp. 260–262, Plates II., III. *Zeits. deuts. geol. Ges.*, vol. xix., 1867, pp. 785–788, Plate XIV. *Ibid.*, vol. xxiii., 1871, pp. 42–46.

[5] *Geol. Mag.*, 1872, pp. 1–10, Plate I., and pp. 536–545. *Ibid.*, 1881, p. 438.

[6] 'Die Krystalliten,' 1875, pp. 122–126, Plate XIII., XIV.

[7] 'British Petrography,' 1888, pp. 344–347, Plate XXXIV.

[8] *Quart. Journ. Geol. Soc.*, vol. xlix, pp. 536–564, Plate XIX.

[9] *Mikroskopische Physiographie der massigen Gesteine*, 1896, pp. 699–702, of 3rd edition.

[10] *Tscherm. Min. Petr. Mitth.*, vol. xiv., 1895, pp. 448–451.

[11] Corstorphine records a rhombic pyroxene as occurring, subordinate to augite, in a pitchstone in An Sloc, in the southern part of the island.

The larger *crystallites* are in the form of minute rods (microlites) or needles, tapering at one end (belonites of Zirkel), and are constantly transparent and of green colour. The belonites are often aggregated into radiate groups, joined at the base, but not so regularly developed as to form perfect stars. Again, they grow attached to, and set perpendicularly upon, the faces of the porphyritic crystals, so as to appear in the slice as a thick fringe. These larger crystallites themselves have in turn served as starting-point for the growth of the much smaller crystallites of what we have styled the second order, and in this way have been built up elaborate fern-like and arborescent growths which give a very remarkable appearance to a thin slice of any of the Arran pitchstones. The mineralogical nature of the green microlites and belonites in these rocks has been the subject of some discussion. In the specimens examined by us the mineral, whenever sufficiently characteristic, seems to be hornblende. The extinction-angles observed were in all cases low, and pleochroism is often to be detected. It is possible that augite occurs in some of the Arran rocks not examined, and indeed Rosenbusch has noted in some cases, though rarely, extinction-angles up to 35°.[3] The largest crystallites show in cross-section characteristic crystal outlines, which are those of hornblende. They are, as Sir J. J. H. Teall[4] has remarked, hollow, the glassy core corresponding in shape with the exterior. In size these larger crystallites vary in different rocks and also within a certain range in a given rock. In different specimens they have a length of ·005 to ·01 inch or ·01 to ·02 inch, with a width rarely more than ·0002 or ·0003 inch. There are often, however, a few rather larger rods, up to ·04 or ·05 inch in length. As a rule, these largest crystallites do not, like the rest, act as the trunks of arborescent and other complex growths.

The much more minute crystallitic growths, which represent the latest effort of crystallization in the pitchstone magma, occur in two ways—disseminated uniformly through the glassy matrix and clustered thickly upon the larger and earlier crystallites to form complex arborescent and other aggregates. In the former case they impart to the general matrix a yellow colour and a somewhat turbid aspect in a thin slice, an appearance resolved by the use of a higher magnification. It is then seen to be due to the presence of an immense number of excessively minute bodies usually in the shape of short rods. With the short rods there may be still smaller bodies in the shape of globulites, and less commonly the globulites occur alone or almost alone (Dun Fionn, 2448; Caisteal Abhail, 2451). The complex growths built up by the aggregation of the minute crystallitic elements about the larger ones assume various forms. A very characteristic one resembles exactly a pine-tree, of which the trunk is made by a belonite and the foliage by a vast number of the smaller bodies. Another beautiful shape is made up by two or three rather small rod-like crystallites of the first order, crossing one another at their middle points, with their four or six extremities bearing complex plumose growths, which unite to form in section a feathery circle having the little rods as diameters. These two forms are well illustrated by specimens from Corrygills and Tormore respectively, and have frequently been figured.[1] The mineralogical nature of the more minute crystallites cannot be investigated directly, for, excepting their greenish-yellow colour, they do not exhibit any optical properties. It may be inferred, however, with high probability, that they are of the same nature as the larger crystallites, and therefore of hornblende. Those which take part in the complex growths have the same appearance as the trunks of the same growths. Further, it cannot be doubted that the minute crystallites disseminated through the glass are identical with those in the aggregates; for an invariable feature of these rocks is a ring of clear colourless glass surrounding each complex growth, as if the fine crystallitic matter which would otherwise have been scattered through this space had been abstracted to make up the aggregate in the centre.

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[1] *See* Sorby, *loc. cit.*, Plate XVIII., Figs. 57-63; Teall, 'British Petrography,' p. 19 (in felspar), and Zirkel, *loc. cit.*, 1867, Plate XIV., Figs. 16 22 (in quartz).

[2] Scott has recorded anorthoclase in the Glen Ashdale pitchstone. In some types felspars resembling chequer albite are seen. G.W.T.

[3] Pyroxene microlites were definitely identified by Scott in the Glen Ashdale pitchstone (Torr an Loisgte). *Op cit. supra*, p. 15. G.W.T.

[4] *Loc. cit.*, p. 345, Plate XXXIV., Fig. 4.

The glass itself, apart from the minute crystallitic bodies with which it is charged, is always clear, colourless, and structureless. It does not, as a rule, show any perlitic structure. Indeed the 'pitchstones,' such as those of Meissen in Saxony, which show best this breaking up by minute curving fissures due to contraction, are mostly lava-flows, while these Arran rocks occur exclusively in the form of dykes and intrusive sills. There are, however, exceptions. A specimen (2451) from a dyke at Caisteal Abhail shows very perfect perlitic fissures, which mostly occur immediately surrounding phenocrysts of quartz and sometimes of felspar.

Many of the rocks show no evident indication of flowing movement in the magma subsequent to the beginning of crystallization; but in others fluxional phenomena are seen, and are of various kinds. Sometimes the porphyritic crystals of felspar are arranged with their long axes parallel to the direction of flow; less commonly the larger crystallites and crystallitic aggregates exhibit a like orientation (Corrygills shore, 111; Cnoc an Fheidh, 6392). Again, in some examples from Tormore (5656, 5657) and elsewhere the matrix of the rock is finely banded, the narrow bands following flow-lines, and being visible as an alternation of fine darker and lighter stripes upon a hand-specimen. In the slices this appearance is seen to arise from the unequal distribution of the crystallites through the glassy matrix. Stellate, plumose, and other groupings occur abundantly in certain bands and only sparsely in others. The more minute crystallitic elements are perhaps equally plentiful in the two cases ; but in the former they are aggregated, leaving the glassy matrix clear, and in the latter they are dispersed, producing a cloudy yellowish appearance.

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[1] *See, e.g.*, Cohen's *Sammlung von Mikrophotographien*, Plate IV., Fig. 1 of 3rd edition, 1899.

The pitchstones of Arran, with those of the other western islands of Scotland and of the north of Ireland, differ from all other known acid rocks in their richness in crystallites of a ferro-magnesian silicate. Though always present, these are not always equally abundant, and the differences may be connected with differences of chemical composition. It is also to be remarked that some of the rocks do, and others do not, carry porphyritic quartz. The analyses of pitchstones and associated rocks given in the earlier Arran Memoir (p. 124) show a certain range of chemical composition, some of the rocks being acid and others sub-acid. Our specimens selected for examination probably belong for the most part to the truly acid type, but one, picked out from the rest on account of its richness in the ferro-magnesian element, is perhaps a *sub-acid* rock. It is from a sill at Brodick School (7537). It does not differ notably from the rest in appearance in a hand-specimen, except that it has a more decided black colour ; but its specific gravity is found to be at 2·45, while a more ordinary variety from Corrygills (110) gives only 2·34. In a thin slice this Brodick rock shows a plexus of closely packed fine fibres imbedded in a brown glass. The fibres seem to be, at least in general, of felspar, and the larger ones show a central core of glass. The smaller are arranged in parallel groups attached to the larger and grown nearly at right angles to them, but there is no special orientation of the groups thus built up. The crowding of these crystallitic elements makes it difficult to examine the interstitial glass, but the brown colour is probably proper to the glass itself and not merely due to globulites.

Doubtless other pitchstones of sub-acid and intermediate composition occur in Arran. Delesse[1] mentions a thick sill in the red sandstones which gave the specific gravities 2·532 and 2·548 in the centre and at the margin respectively. The corresponding percentages of water were only 1·65 and 1·75, which are remarkably low figures.

Numerous geologists have noticed the occurrence in Arran of *felsitic rocks* in close association with pitchstones. In the older literature these rocks figure usually under the names ‘ hornstone ’ and ‘ claystone.’ Some which have been analysed have a chemical composition not essentially different from that of the pitchstones,[2] and the intimate association of the two rocks decidedly suggests that they are closely cognate and are in some cases parts of the same rock-body, the one having assumed a finely crystalline and the other a vitreous state. Assuming this, it remains a question to be considered in any given case whether the finely crystalline texture

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Ann. des Mines (5), vol. xiii., 1858, p. 356.

[2] ‘ Geology of North Arran, etc.’, (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 124.

is original or is the result of devitrification of a pitchstone. In an example on Cir Mhòr carefully studied by Prof. Judd, that writer arrived at the former conclusion,[1] but the other alternative may be entertained in other instances. The remarkable microstructure of the pitchstones may not improbably become obscured or obliterated by secondary changes when the glassy character is lost, and the absence of perlitic fissures in most of the Arran pitchstones usually precludes a criterion which has often been relied upon in other districts as indicating a formerly vitreous condition in rocks now cryptocrystalline or microcrystalline.

There are, nevertheless, specimens in our collection which give many indications of having originally been pitchstones and having lost their glassy texture, though the alteration evinced has been in general of a more radical kind than mere devitrification.

An interesting specimen comes from a quarter of a mile north-east of Kilmichael, Glen Cloy (7539). It is a dull-grey, compact rock, with numerous minute white spots, which look like spherulites. A thin slice shows in natural light a vast number of little needles answering exactly to those seen in the pitchstones (Zirkel's belonites), but replaced by some chloritic or ferruginous substance. There are also abundant relics of the more minute crystallitic bodies attached like branches and twigs to these trunks, though the delicate arborescent growths which have probably been present have been in great measure destroyed, and clotted patches of the same ferruginous material represent the destroyed crystallites. Polarized light shows that the groundmass is not glassy, but consists of irregularly interlocking and interlacing crystalline areas. An imperfect radiate arrangement is seen in places, but no complete spherulites. The rock has probably been a pitchstone, and has undergone devitrification and other changes. Some little interstitial areas of clear quartz must be regarded as of secondary origin.

A specimen from a dyke north of Torr Righ Mòr (6405) is a dull compact rock mottled with pink and white streaks and with little scattered quartz-crystals. It has something of a fissile structure, corresponding with very evident fluxion-lines. In the slice we see well-developed perlitic fissures traversing the rock everywhere, and, with other circumstances, leaving little doubt that it has been originally a pitchstone. There are still little irregular brown patches which are dark between crossed nicols, and are crowded with what have presumably been crystallites, now replaced by reddish-brown ferruginous matter. The rest of the slice shows double refraction in a blotchy irregular fashion. In natural light there are clearer spots, often coalescing with darker yellowish interspaces. The spots often polarize as individuals. Another rock, comparable with this, comes from Tormore (6404). This also shows marked flow-structure, with bands of pale green and pale yellow. It has a very compact, almost porcellanous, appearance, and is one of Jameson's hornstones. There are here no perlitic fissures, except occasionally surrounding the little porphyritic crystals. In natural light the appearance is otherwise very similar to that of the preceding rock, the clearer spots and yellow interspaces being strongly marked. Between crossed nicols, however, the groundmass breaks up into a much more fine-textured aggregate than before. The blotchy or spotted appearance of these and similar rocks seems to be connected with changes other than mere devitrification. There are, however, rocks which show no such peculiarity, and in which the only noticeable change from the presumed original pitchstone is the resolution of the glass into minutely crystalline elements.

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[1] *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, p. 551. The expression 'primary devitrification' in this connection seems to be confusing, since devitrification is predicable only of what was once a glass.

There are other cases of the association of felsitic rocks with pitchstones in which the two rocks must be considered to represent distinct intrusions. An instructive example is a rock from a dyke in Glen Dubh, 100 yards above its junction with Glen Ormidale. This is a light-grey, compact rock with minute quartz-grains, enclosing rounded patches up to three-quarters of an inch diameter of a darker grey colour. These patches are seen in the slice (7540) to be of the same general character as the matrix, both having a very finely crystalline texture, though with rather different structures. The grey matrix includes, however, other and smaller dark patches, which have all the appearance of a pitchstone under the microscope, except that the glassy base is devitrified, and only the larger and stouter crystallitic bodies retain their shape and groupings.

One well-known dyke on Corrygills shore may be mentioned here as being associated with the pitchstones, though there is nothing to indicate that it has itself been vitreous. Since the rock has been described and figured more than once,[1] no detailed account is necessary here. It is a spherulitic felsite of dull-grey aspect, the little spherulites appearing in our specimen (3323) as dead white spots one-fortieth to one-eighth of an inch in diameter, often with a dark nucleus and a dark border. There is a flow structure, partly marked by lines of spherulites. The appearance in a thin slice, and especially the blotchy or spotted character already remarked in other rocks, are well shown in Teall's coloured plate, and the rock seems to have suffered alteration of the kind already pointed out in other cases. The spherulites, which make up most of the bulk, have had their radiating fibres replaced by irregularly interlocking narrow sectors, or in the central portion by a merely granular aggregate. This latter structure is seen also in the interspaces between the spherulites. In our specimen, from the edge of the dyke, the flow lines are seen to run uninterruptedly through the spherulites. A.H.

The pitchstones of Arran may be provisionally classified into four petrographical types, which may be designated as the Corrygills, Glen Shurig, Tormore, and Glen Cloy types respectively. One example of each type has been analysed, and is described below.

Corrygills Type.—The analysed rock (25614) is from the lower ledge of the Dun Fionn pitchstone sills (p. 213). It is a dark, olive-green, non-porphyritic pitchstone, with a marked platy fracture. In thin section it reveals a pale biscuit-coloured glass crowded with pleochroic green needles and feathery scopulites. The extinction-angle of these needles varies between 10° and 15° in a great majority of cases, although one of 24° was measured. There does not seem any reason to doubt Dr. Harker's identification of them as hornblende (p. 225). Interspersed amongst the microlites are numerous pale-green flakes of irregular shapes which are faintly-polarizing. These are sometimes bounded by straight prismatic edges and have scopulitic terminations. They probably represent sections parallel to the flat faces of mineral plates of the same nature as the acicular microlites. Finally there are a very few, tiny, irregular spherulites. The refractive index of the glass is 1·492 ± ·002.

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[1] Allport, *Geol. Mag.*, 1872, pp. 540, 541 ; Bonney, *Geol. Mag.*, 1877, p. 506, with Fig. ; Teall, 'British Petrography,' 1888, Plate XXXIX., Fig. 1.

The majority of the pitchstone occurrences in the Corrygills district belong to this type. The North Corrygills dyke (25068), and the spherulitic rocks on the Corrygills shore (19, 3323, 3323A, 24363) belong here, as do also rocks from the Corrygills shore (? Clauchland shore) (2454), from the southern slope of Dun Fionn (24386), and from Monamore Glen (A112, B112). Three slices from the Dun Fionn occurrences (2448–50) are identical with that of the analysed rock described above.

Tormore and Glen Shurig Types.—These types are very much alike and may be described together. They are porphyritic pitchstones, and in thin section show phenocrysts of quartz, felspars, pyroxenes, and iron-olivine (fayalite), embedded in a colourless or pale-yellow glass crowded with microlites and crystallites of various kinds. The *Tormore* type is relatively rich in pyroxenes as compared with iron-olivine; on the other hand, the Glen Shurig type exhibits a relatively large concentration of iron-olivine. Examples may occasionally be found almost free from both minerals.

In the analysed rock from Judd's No. II. dyke on the Tormore shore (25621) the glassy matrix is pale biscuit in colour, and is crowded with minute specks except in areas adjacent to the numerous green microlites, which show 'courts of crystallization.' The refractive index of the glass is 1·495 ± ·002. The phenocrysts include quartz, felspars, pyroxenes, iron-olivine, and magnetite. The quartz-crystals are invariably corroded, rounded, and embayed. The felspars, too, while displaying more euhedrism than the quartz, have nevertheless suffered some corrosion, and exhibit rounded corners and edges. While the majority of the felspar sections are perfectly clear and transparent, a few are turbid like the xenocrystic felspars of other Arran rocks. The mean refractive index of the felspars is 1·55, and the maximum extinction angle of the albite twinning is 17°; the composition is therefore determined as andesine ($Ab_{66}An_{34}$). Many of the crystals are zonal, the exterior zone giving straight extinction (oligoclase). Hence the bulk-composition of the felspar is probably less calcic than is indicated by the composition of the kernels.[1] The felspar crystals often enclose pyroxene and magnetite, and are associated with them in a 'together-swimming' or synneusis (Vogt) structure, producing a mineral combination recalling that of the tholeiites with which this rock forms composite dykes.

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[1] It has often been stated that 'sanidine,' 'soda-orthoclase,' 'anorthoclase,' etc., occur in the Arran pitchstones; and while not asserting their complete

The pyroxenes include both orthorhombic and monoclinic varieties. The orthorhombic variety is a pale or colourless enstatite giving elongated, cross-fractured, prismatic sections. The augite is colourless to pale green, with a maximum extinction-angle of 43° in prismatic sections. The pyroxene crystals almost invariably enclose magnetite, especially around their peripheries.

The iron-olivine (fayalite) forms anhedral crystals which tend to alter to a deep-green serpentine. It is very subordinate in quantity to the pyroxenes in the Tormore rock, but in the Glen Shurig pitchstone it becomes the most important coloured mineral (25615). In this rock it forms large, anhedral, honey-coloured crystals, which are associated with felspars, green clinopyroxene (ægirine-augite), a little enstatite, and magnetite in synneutic groups. The glass entangled between these crystal groups is biscuit-coloured, and is free from crystallites, whereas the glass outside them is colourless and full of crystallites. The refractive index of the clear glass is 1·495 ± ·002. Dr. A. Scott has given a full description of the Glen Shurig pitchstone, with illustrations showing the glomeroporphyritic aggregates and the fayalite crystals.[1] He also first noted and studied the occurrence of fayalite in the Arran pitchstones.[2]

It is not possible in this place to enter on a full discussion of the origin of iron-olivine in these silica-rich rocks, and we therefore present only a few brief notes referring to recent views on the subject. Scott suggested two possible modes of origin for the fayalite: (*a*) the glomeroporphyritic aggregates may be partly or wholly of xenolithic origin, the olivine crystallizing from a basic material subsequently inundated by acid magma; (*b*) the formation of the olivine may be analogous to that of magnetite in a granite. Scott believed the first-named hypothesis the more satisfactory of the two. In a recent discussion of the presence of olivine in acid igneous rocks containing a large excess of free silica, Dr. L. Hawkes[3] shows that the only common feature in these olivine-bearing rocks is their poverty in magnesia. He favours the view that, like magnetite and the ferro-magnesian silicates, fayalite is only slightly soluble in siliceous magmas, and forms as a normal magmatic constituent from melts of appropriate composition. As in the Icelandic rock described by Hawkes and in the other rock types cited by him, the olivine in the Arran pitchstone does not show reactional effects, although it is enveloped by a silica-rich and water-rich glass. Nevertheless iron metasilicate does form in these rocks much more often than the orthosilicate, and with CaO and MgO produces pyroxenes,

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absence, it is well to emphasize their rarity. On close examination the felspars almost invariably show multiple twin striations, and refractive index tests show that they are plagioclases.

[1] *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 147–150, Plate XV.

[2] *Ibid.*, vol. xv., part i., 1914, pp. 18–20.

[3] 'On an Olivine-dacite in the Tertiary Volcanic Series of Eastern Iceland,' *Quart. Journ. Geol. Soc.*, vol. lxxx., part iv., 1924, pp. 549–567.

as pointed out by Fenner.[1] Hence the presence of the orthosilicate is not due to the inhibition of the formation of iron metasilicate. Fenner favours the view that the formation of silica-poor ferro-magnesian minerals in acid igneous rocks is due, partly at least, to the presence of fugitive or volatile constituents, a view supported by the common occurrence of fayalite in lithophysæ. The Arran pitchstones are rich in combined water (*see* analyses, p. 234), and differences in the concentration of volatile constituents are indicated by different states of the glassy groundmass within and near the glomeroporphyritic aggregates of which fayalite is a prominent constituent. The following are the pitchstones in the Survey collection which conform more or less to the above description. There are numerous variations in the number and relative abundance of the phenocrystic minerals, and in the nature of the glassy groundmass: Cir Mhòr (25071, 25617), almost free from fayalite, and showing the hyalite-tridymite investments described by Judd,[2] and discussed by Scott[3]; Caisteal Abhail (2451–2, 3324–5); Brodick Schoolhouse (2453, 3321, 7537, 25616), a variable type, some bands being practically free from phenocrysts; the main western headwater of the Lag a' Bheith (25046); head of Allt nan Clach, south of Tighvein (24876); Torr an Loisgte (24870); the stream west of Torr an Loisgte (24869)—the felspar in this rock appears to be distinctly more sodic than that of the type Tormore rock; Cnoc Mòr, Glen Ashdale (24872); Cnoc an Fheidh, Allt Dhepin (6392); Allt an t-Sluic, Kilpatrick (6380, 25081); Allt na Craoibhe, Kilpatrick (25082); Tormore (3326, 5656–7)—many felspar microphenocrysts but very poor in ferro-magnesian minerals, as is also Judd's No. I. Dyke (26520) and No. III. dyke, Tormore shore (25624).

Glen Cloy Type.—This type is somewhat more basic than the pitchstones described above. The glassy base is darker, more opaque, and has a higher refractive index than that of either the Corrygills or Tormore types ($n = 1{\cdot}503 \pm {\cdot}002$ in 24391, Glen Cloy). In devitrification there is a tendency to develop spherulitic or variolitic structures, showing felspathic fibres with irregular interstitial quartz (24390), or a meshwork of skeletal fibres or needles of craignuritic type, in which needles of chloritized pyroxene (?) play a prominent part (25060, 7539).

The Survey collection has examples of these rocks from four localities: Glen Dubh, a dyke 24 feet wide 100 yards above the confluence of Glen Dubh Water with the Glen Ormidale Water (7540, 24389, 24453—the last is the analysed rock); Glen Cloy Water, one mile west of Invercloy, Brodick (24390–1), a sill which has been fully described by Dr. A. Scott[4]; Kilmichael Wood, Glen Cloy (7539); and from a 5-foot sill in the main western headwater of the Lag a' Bheith (25060–1, *see* p. 137).

The phenocrysts present are quartz, felspars, more or less altered ferro-magnesian minerals, and magnetite. Quartz does not occur in the more glassy parts of the Glen Cloy (24391), or the Lag a' Bheith sill (25061), but it is abundant in the Glen Dubh dyke both as perfectly euhedral crystals, and as irregular, embayed, and corroded forms. The felspar in the Glen Cloy sill (24391) is a clear, euhedral, acid andesine of the same characters as in the other types of pitchstone; but in the Glen Dubh dyke (24389) and the Lag a' Bheith sill (25061) it is either untwinned or simply-twinned, and but rarely shows any trace of albite striations. The mean refractive index of this felspar in (25061) is about 1·535, hence it must be regarded as oligoclase.

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[1] 'The Katmai Magmatic Province,' *Journ. Geol.*, vol. xxxiv., 1926, p. 699.

[2] *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, p. 550.

[3] *Trans. Geol. Soc. Glasgow*, vol. xv., part i., 1914, pp. 26–27.

[4] *Trans. Geol. Soc. Glasgow*, vol. xv., part ii., 1915, pp. 140–147.

A green ægirine-augite is identifiable in the Glen Cloy pitchstone (24391), the crystals being frequently broken up into granular aggregates. In all the other rocks the ferro-magnesian minerals have been thoroughly chloritized.

In most of these rocks the phenocrysts are grouped in the usual glomeroporphyritic aggregates. The Glen Dubh dyke (7540, 24453) occasionally shows little angular xenoliths of a variolitic tholeiite, as though the magma had disrupted a tholeiite dyke in its upward passage. This rock has been described by Dr. A. Harker (p. 229).

Many of the felsites which are closely associated with the pitchstones in the field have microstructures that clearly show they are due to the devitrification of the pitchstones (p. 227). The grouping of the phenocrysts is the same as in the pitchstones; occasionally microlites and crystallites are still discernible; while in the Cir Mhòr felsite (25618) the hyalite investments around the phenocrysts have been retained. In another specimen of the same rock, however, these traces are almost entirely lost, and the microtexture resembles that of many Arran felsites which are not obviously connected with pitchstones (25072). Felsites in the Survey collection which are associated with pitchstone are: Torr an Loisgte (24871), and Judd's No. II. dyke, Tormore shore (25623), in addition to the Cir Mhòr slices mentioned above. Another felsite which appears to be a devitrified pitchstone is a dyke from the tributary to the Allt Dhepin east of Cnoc an Fheidh (24875).

Three other felsite occurrences which deserve mention (apart from those discussed in Dr. A. Harker's account, p. 227) are the Glen Shurig dyke (24370), the sill at Corrygills Point (25042), and the little plug of the Cheese Hole, Dippin (6363). The Glen Shurig dyke is a remarkably compact, chalk-like felsite in hand-specimens. In thin section it shows a uniform, cryptocrystalline, 'felsitic' material, in which only quartz and an occasional shred of chloritic matter can be identified. The Corrygills rock shows a few microphenocrysts of quartz embedded in a groundmass made up largely of a fine micrographic intergrowth of quartz and turbid alkali-felspar. The Cheese Hole plug in thin section discloses a dense, turbid, cryptocrystalline groundmass, in which only a few shreds of quartz can be identified. In this matrix are embedded little, square, rectangular, or rhomboidal crystals of orthoclase.

Chemical Composition.—The analyses of three typical Arran pitchstones, those of Corrygills, Glen Shurig, and Tormore, together with an analysis of the Glen Dubh felsite which is believed to be a devitrified pitchstone, are tabulated for comparison below.

TABLE VII

	14.	R.	15.	16.	S.	6.	17.
SiO_2	73·20	73·12	72·33	71·51	71·53	69·26	72·37
Al_2O_3.. ..	10·75	12·44	10·45	10·55	12·00	11·60	11·64
Fe_2O_3.. ..	·95	2·09	1·00	·79	2·90	1·31	1·42
FeO	1·02	1·65	2·14	2·22	2·02	2·57	1·08
MgO	·15	·14	·11	·52	·62	1·10	·52
CaO	·76	·88	1·44	1·52	2·33	2·61	1·30
Na_2O	3·78	3·90	4·09	4·12	4·27	2·08	4·15
K_2O	4·20	4·67	3·49	3·48	3·06	3·88	3·98
$H_2O>105°$ ..	4·52	·24	4·02	4·07	·36	1·67	ign.
$H_2O<105°$ ..	·18	·25	·16	·19	·13	1·61	4·86
TiO_2	·16	·39	·30	·33	·64	·45	—
P_2O_5	·19	·09	·16	·24	·17	·10	—
MnO	·37	·17	·50	·42	·36	·45	—
CO_2	—	·05	—	—	nt. fd.	1·76	—
FeS_2	—	nt. fd.	—	—	—	nt. fd.	—
(Ni, Co)O ..	nt. fd.	nt. fd.	nt. fd.	nt. fd.	·02	nt. fd.	—
BaO	·05	nt. fd.	·08	·08	·08	nt. fd.	—
Li_2O	nt. fd.	nt. fd.	tr.	nt. fd.	? tr.	nt. fd.	—
Cr_2O_3.. ..	—	—	—	—	nt. fd.	—	—
S	—	—	—	—	nt. fd.	—	—
V_2O_3	—	—	—	—	nt. fd.	—	—
	100·28	100·08	100·27	100·04	100·49	100·45	101·32

14. (25614. Lab. No. 850.) Pitchstone (Corrygills type), sill, lower pitchstone scarp above path near South Corrygills, quarter of a mile W.N.W. of Dun Fionn, Arran. *Anal.* E. G. Radley.

R. (14843. Lab. No. 372.) Granophyre of Beinn a' Ghraig ring dyke, Benmore Lodge, western end of Loch Bà, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir*, 1924, p. 20.

15. (25615. Lab. No. 851.) Olivine-bearing pitchstone (Glen Shurig type), dyke, farm road 65 yards from String Road, half a mile south-west of Brodick Church, Arran. *Anal.* E. G. Radley.

16. (25621. Lab. No. 852.) Pitchstone with ortho- and clino-pyroxenes, and olivine, Judd's No. II. dyke (*see* map, p. 219), Tormore shore, south of Machrie Bay, Arran. *Anal.* E. G. Radley.

S. (11734.) Porphyritic quartz-felsite, intrusive sheet, Ashval, Rum. *Anal.* W. Pollard. Quoted from A. Harker, 'The Geology of the Small Isles of Inverness-shire,' (Explanation of Sheet 60), *Mem. Geol. Surv. Scotland*, 1908, p. 139.

6. (24453. Lab. No. 823.) Felsite (devitrified pitchstone), 24-foot dyke in Glen Dubh Water, 100 yards above confluence with Glen Ormidale Water, and 825 yards W. 37° S. of Kilmichael, Brodick, Arran. *Anal.* E. G. Radley.

17. Porphyritic pitchstone, centre of Cir Mhòr dyke. *Anal.* E. C. Thomson. Quoted from J. W. Judd, 'On Composite Dykes in Arran,' *Quart. Journ. Geol. Soc.*, vol. xlix., 1893, p. 545.

The chemical differences between the Corrygills, Tormore, and Glen Shurig pitchstones are relatively slight. The Corrygills pitchstone is the most siliceous, and in it soda is subordinate to potash. The Glen Shurig and Tormore pitchstones are almost identical, although the former is slightly the more siliceous of the two, as is well shown by the comparison of certain items of the norms in the table below. In these rocks the relation between soda and potash is the opposite of that in the Corrygills pitchstone. The greater abundance of ferro-magnesian minerals in the Glen Shurig and Tormore pitchstones, as compared with the Corrygills type, is reflected in their greater amount of FeO and MgO. Another notable chemical feature of the pitchstones is that over 4 per cent. of water is retained in these glasses, an effect certainly due to their excessively rapid solidification.

	% Salic Minerals.	Q.	or.	ab.	an.
Pitchstone, Corrygills ..	90·4	33·4	25·0	32·0	—
Pitchstone, Glen Shurig	87·2	32·1	20·6	34·6	—
Pitchstone, Tormore ..	85·9	30·5	20·6	34·6	·3
Pitchstone, Cir Mhòr ..	90·1	30·3	23·3	35·1	1·4
Pitchstone, Glen Dubh..	83·6	38·5	22·8	17·8	·8

Amongst Arran rocks the Corrygills pitchstone compares best with the granophyre of the Central Ring Complex (Table V., 9, p. 192), although this rock is richer in silica; and with the Bennan quartz-porphyry (Table VI., 11, p. 204), although the latter rock is more potassic. The Glen Shurig and Tormore pitchstones resemble the Goatfell granite (Table III., 7, p. 155), although the latter is at once more siliceous and more potassic than the pitchstones. They have also a fairly close resemblance to the felsites of the craignurite series.

The Glen Dubh felsite or devitrified pitchstone is the most ‘ basic ’ of the series, as is shown by its lower silica and alkalies, with higher ferrous oxide, magnesia, and lime, as compared with the other pitchstones. Its affinities are clearly with the rocks at the ‘ acid ’ end of the craignurite series, as is shown by the analyses tabulated for comparison with it in Table II., p. 147. Relatively to soda these rocks are more potassic than the pitchstones, and in spite of lower silica they are richer in normative quartz.

With regard to rocks of the Kainozoic igneous province of the Western Isles outside Arran, the Corrygills pitchstone compares well with the granophyre of the Beinn a’ Ghraig ring dyke in Mull (Table VII., R); and the Glen Shurig and Tormore types compare in chemical composition with a porphyritic quartz-felsite from Rum (Table VII., S).

Of the earlier pitchstone and felsite analyses tabulated on p. 124 of the ‘ Geology of North Arran, etc.’ (*Mem. Geol. Surv.*), 1903, owing to incompleteness and analytical defects, only one, that of the Cir Mhòr pitchstone, is worth preserving. The summation even of this analysis is much too high for present-day standards. It is recorded in Table VII., 17, and should be compared with 15 and 16, the analyses of the Glen Shurig and Tormore pitchstones.

Riebeckite-Orthophyre of Holy Island (p. 222).—The fresh rock is of dark-grey colour, very compact, with minute, flashing, cleavage flakes of felspar, and in the field closely resembles some types of phonolite.

Microscopically the rock (24461) consists of microporphyritic sanidine in a groundmass of smaller lathy crystals of the same mineral, with riebeckite, ægirine-augite, and iron-ores, and interspersed with a few irregular areas of quartz. The sanidine occurs in euhedral, rectangular, simply-twinned crystals evenly and numerously scattered all over the field. The groundmass consists mainly of subhedral laths of sanidine, closely packed and in places with good flow orientation. Riebeckite occurs mostly in the well-known ophitic, mossy, or sponge-like masses, but there are also a few parallel-sided prismatic crystals. The mineral is often quite fresh, showing the usual pleochroism from indigo-blue, through greenish-blue, to yellowish-green. Occasionally it is altered to an indeterminate yellow mineral. There are also numerous, green, prismatic crystals of ægirine-augite, with an extinction angle of between 30° and 40°. The short, stumpy, rectangular crystals of sanidine dominate the texture. As they show little approach to parallel arrangement the texture is regarded as orthophyric rather than trachytic ; and this, together with the intrusive mode of occurrence, renders the term riebeckite-orthophyre more suitable than riebeckite-trachyte.

The closest geological and petrological affinities of the Holy Island rock in the Clyde region are with the riebeckite-microgranite of Ailsa Craig, 17 miles to the southward. The chemical composition of these rocks is shown in Table VIII., where an analysis of the Holy Island riebeckite-orthophyre is tabulated for comparison with two analyses of the Ailsa Craig riebeckite-microgranite, one by Raoult, in Prof. Lacroix's work on Rockall, and the other by Mr. A. G. Lowndes.

The Holy Island rock contains the largest amount of alkalies yet recorded in any analysed Arran rock. The soda is in excess of potash, as it is also in Raoult's analysis of the Ailsa Craig rock, although in Mr. Lowndes' incomplete analysis this relation is reversed. The silica is high, although the Ailsa Craig rock is even richer in this constituent, corresponding to its greater richness in modal quartz. These two riebeckite-bearing rocks may be further compared with an ægirine-granite, that of Rockall, which may be regarded as belonging to the same petrographical province (Table VIII., W.). While the alkalies and silica are closely comparable, the greater abundance of ægirine (and riebeckite in some specimens) in the Rockall type is shown by a diminution in the amount of alumina, with a corresponding increase in ferric oxide, as compared with the Scottish rocks.

The only other rock which compares at all closely with that of the Holy Island is a trachyte from Mull, a plug in a volcanic vent (Table VIII., V.). This rock also contains aegirine-augite and a

TABLE VIII

	18.	T.	U.	V.	W.
SiO_2	68·38	71·56	69·40	63·12	66·62
Al_2O_3	15·87	14·02	15·73	15·44	11·96
Fe_2O_3	1·02	1·26	3·21	1·73	4·19
FeO	1·42	1·46	—	3·53	3·54
MgO	·04	·21	·00	·62	·31
CaO	1·04	·42	·21	1·31	1·32
Na_2O	5·70	6·46	4·75	5·81	6·20
K_2O	4·65	3·97	5·76	5·36	4·06
$H_2O>105^\circ$ ..	·56	·43	—	·44	·22
$H_2O<105^\circ$ ..	·30	·08	—	·14	·08
TiO_2	·24	·28	—	·51	·79
P_2O_5	·26	tr.	—	·25	·21
MnO	·37	—	—	·27	·10
CO_2	·04	—	—	1·89	—
ZrO_2	·06	—	—	—	·38
$(Ce, Y)_2O_3$ ..	—	—	—	—	·18
FeS_2	nt. fd.	—	—	nt. fd.	—
$(Ni, Co)O$	·03	—	—	nt. fd.	—
BaO	·03	—	—	nt. fd.	—
Li_2O	nt. fd.	—	—	nt. fd.	—
	100·01	100·15	99·06	100·42	100·16

18. (24461. Lab. No. 831.) Riebeckite-orthophyre, sill, Creag Liath, half a mile slightly east of north of the Lighthouse on the south-west point of Holy Island, Arran. *Anal.* E. G. Radley.

T. Riebeckite-microgranite, Ailsa Craig, Firth of Clyde. *Anal.* Raoult. Quoted from A. Lacroix, *Comptes Rendus*, Paris, tome 177, 1923, pp. 437–438.

U. Riebeckite-microgranite, Ailsa Craig, Firth of Clyde. *Anal.* A. G. Lowndes, *Geol. Mag.*, vol. lx., 1923, p. 268.

V. (14821A. Lab. No. 368.) Trachyte, plug in vent, Bráigh a' Choir' Mhoir, west of Salen, Mull. *Anal.* E. G. Radley. Quoted from the *Mull Memoir*, 1924, p. 27.

W. Ægirine-granite, Rockall Bank, dredged 12 miles north of Rockall. Quoted from A. Lacroix, *Comptes Rendus*, Paris, tome 177, 1923, pp. 437–440.

soda-amphibole allied to riebeckite. It differs from the Holy Island rock in being much poorer in silica. The above-mentioned rocks are mineralogically compared in the table below, which is based on the normative values of the various constituents.

	Salic %	Q.	or.	ab.	an.	æg.
Riebeckite-orthophyre, Holy Island	94·5	14·8	27·8	48·2	3·6	—
Riebeckite-microgranite, Ailsa Craig	91·5	18·4	23·3	49·8	—	4·2
Trachyte, Mull	85·4	4·5	31·7	49·2	—	—
Ægirine-granite, Rockall Bank ..	77·5	13·7	24·5	38·8	—	12·0

G.W.T.

CHAPTER XVI

THE KAINOZOIC IGNEOUS ROCKS (*continued*)

THE ARRAN DYKE SWARM

INTRODUCTION

THE Arran dykes are replete with geological interest and petrological importance. Their extraordinary numbers and their variety of geological occurrence have attracted the attention of geologists from the time of Ami Boué onwards. Since in his wonderfully detailed field-maps on the six-inch scale, the late W. Gunn gave not only the exact directions, but also the thicknesses, of hundreds of dykes, statistical analysis of these data yields material for a full comparison of the Arran dykes with those of the Mull and Skye centres. The only other attempt in this direction is the elaborate tabular classification of 149 Arran dykes by L. A. Necker de Saussure,[1] of which mention has already been made (p. 13).

A thick congregation or assemblage of dykes stretching across country in a more or less constant direction, or arranged radially about a common centre, has been called a *swarm*. The Kainozoic dyke swarms of the West of Scotland are connected with the centres of igneous activity in Skye, Rum, Mull, and Arran,[2] and have a general N.W. to S.E. trend, although dykes in other directions may be locally abundant. The Mull Swarm, beginning in Coll, has its focus in the igneous centre of south-eastern Mull, and continues with a general south-easterly trend across Lorne, Loch Awe, upper Loch Fyne, to the Clyde estuary between Cowal and the Renfrewshire–Ayrshire mainland. The country between the Mull and Arran Swarms, including the Ross of Mull, the northern part of Jura, Knapdale, and lower Loch Fyne, is relatively poor in dykes.[3] The Arran Swarm comes to the south-west of this relatively barren zone. Beginning in Colonsay, it stretches across southern Jura, Islay, Gigha, the central part of the Kintyre peninsula, and Arran, where the dykes become extremely abundant, indicating that the focus of the swarm is here reached. The general direction of the swarm across Islay, Jura, and Kintyre, is N.W. to S.E., but in Arran the trend changes gradually to N.N.W. to S.S.E. The latter direction is now maintained for the southern part of the dyke swarm, which may be traced across Ailsa Craig to the mainland coast between Girvan and Ballantrae. According to the published geological maps the Arran dyke swarm fades out a few miles to the south of this region, as no dykes of the Kainozoic direction are mapped in southern Ayrshire and Wigtownshire on the direct line of continuation of the swarm. The Arran Swarm thus suffers a decided change of direction from N.W. to N.N.W. at its focus in Arran.

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[1] 'Documents sur les Dykes de Trap d'une partie de l'Ile d'Arran,' *Trans. Roy. Soc. Edinburgh*, vol. xiv., part ii., 1840, pp. 677–698.

[2] *Mull Memoir*, 1924, ch. xxxiv.

[3] *Ibid.*, map, p. 357.

Special features of the dykes will be dealt with in succeeding sections of this chapter.

COMPONENTS OF THE ARRAN DYKE SWARM

While the Arran dyke swarm may be held to comprise all Kainozoic dykes of whatever direction, composition, or age, within the island, the principal component is an immense number of basaltic dykes which belong to a late stage of the igneous activity. There are undoubtedly, however, dykes belonging to each main phase of the Kainozoic igneous period. Thus some of the analcite-olivine-dolerite or crinanite dykes belong to the early period of basaltic eruption; others, of quartz-dolerite, craignurite, or felsite composition, were no doubt connected with the intrusion of the great suite of quartz-dolerite sills (Chapter XII). The intrusions of the northern granite and the Central Ring Complex were also probably attended by dyke injection; and many of the still later acid intrusions are in the form of dykes. These rocks have already been described in the preceding chapter under the headings of quartz-porphyry, felsite, and pitchstone.

The greater number of dykes in the swarm belong, however, to a very late phase of the igneous activity, and cut all other Kainozoic igneous bodies except a few acid sills, such as that of Holy Island. It is a matter of extreme difficulty to disentangle the various dyke periods, not only because of the general scarcity of critical and decisive sections, but also because of the recurrence of identical, or almost identical, rock types at different periods. The above statements are based mainly on petrographic evidence, and much more field-work will be necessary in order to substantiate them fully. The field evidence as to age relations will be given in a subsequent section.

A short sketch of the broad petrographical features and classification of the Arran dykes may be conveniently given here as a necessary preliminary to the discussion of their directional, age, and tectonic characters. The rocks correspond closely on the whole to the types described from the Mull Swarm. Firstly there is a group of olivine-basalts, olivine-dolerites, and crinanites, of plateau-basalt type,[1] containing labradorite, purplish augite, olivine, and iron-ores, with interstitial analcite and radial zeolites in the crinanite section. These rocks usually have an ophitic texture, are non-porphyritic, and rarely develop glassy matter even on the rapidly-cooled margins of dykes. In some of the coarser doleritic types devoid of analcite, the augite is of somewhat paler tint, olivine dwindles in amount, and the rocks thus approach closely to the coarser and more basic types amongst the quartz-dolerite–tholeiite group. There were probably two surges of this magma; one at the beginning of the

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[1] *Mull Memoir*, 1924, p. 368.

Kainozoic igneous period, corresponding in time and petrographical character to those remnants of the plateau-basalt episode that are involved in the Central Ring Complex (p. 181); the other occurred towards the end of the igneous period, but preceded the appearance of the later injections of the quartz-dolerite–tholeiite magma. The first group generally consists of coarse-textured, analcite-bearing rocks occurring in thick dykes. The darker minerals are segregated to some extent, producing a coarse maculation on the weathered surface which renders this type easily recognizable in the field as 'spotty crinanite.' The dykes of the later group are generally thin; the rocks are rich in olivine and occasionally analcite, possess a deeply-coloured purple augite, and have a fine ophitic texture. Unlike the rocks of the quartz-dolerite–tholeiite group described later, the rocks derived from the plateau-basalt magma remain very uniform in type, and show little tendency towards differentiation.

There also occurs amongst the dykes a small sub-group of porphyritic basalts and dolerites of varying characters, but united in the abundance of large felspar phenocrysts, which may correspond to the dykes of 'porphyritic central-lava' type described from Mull.[1] Some examples, however, may perhaps be more correctly described as highly porphyritic members of the tholeiite group.

The great majority of the Arran dykes belong to an oversaturated group which, from its most abundant types, may be designated as the quartz-dolerite–tholeiite group. These rocks are characterized by their wide compositional and textural range. The minerals present are basic plagioclase (labradorite to anorthite), a pale diopsidic augite with occasionally uniaxial augite (or enstatite-augite) and orthopyroxenes, iron-ores, quartz, and alkali-felspar, with the two last-named minerals becoming abundant in the more acid varieties. Intergranular (in the quartz-dolerites, etc.), and intersertal (in the tholeiites) textures are extremely common; but ophitic texture only occurs in the coarser and more basic members of the group. A holocrystalline series with a general intergranular or occasionally an ophitic texture, and ranging from olivine-dolerite or olivine-basalt, dolerite or basalt, quartz-dolerite or quartz-basalt, to craignurite or 'porphyrite,' in order of decreasing basicity, may be distinguished from a parallel series with a certain amount of glassy base and an intersertal texture, of which the members are olivine-tholeiite (Largs type),[2] olivine-tholeiite (Salen type),[3] porphyritic olivine-tholeiite (Corrie type),[4] tholeiite (Brunton type),[5] and tholeiite (Talaidh type),[6] corresponding generally to the compositional range of the holocrystalline types as given above. Unlike the olivine-dolerite–crinanite group there is a marked tendency in these rocks for the production of glassy matter; and when glass becomes a prominent constituent a third series of textural types parallel to those given above may be formulated. Some of these rocks have been given special names, and are, in order of decreasing basicity, tachylyte, leidleite,[1] cumbraite,[2] and inninmorite.[3] A variolitic texture may occur in any of these rocks, and the variolitic and tachylytic types are often found on the margins of the tholeiite dykes.

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[1] *Mull Memoir*, 1924, p. 369.

[2] G. W. Tyrrell, 'Some Tertiary Dykes of the Clyde Area', *Geol. Mag.*, 1917, p. 353.

[3] *Mull Memoir*, 1924, p. 370.

[4] Tyrrell, *op. cit.*, p. 352.

[5] *Mull Memoir*, p. 372.

[6] *Ibid.*, p. 284.

Closely associated with the above rocks in composite dykes are certain acid types, quartz-porphyries, felsites, and pitchstones, which reveal their consanguinity with the quartz-dolerite–tholeiite group by the relative abundance of plagioclase felspar and pyroxenes. Felsites and pitchstones, not so clearly related to the quartz-dolerite–tholeiite group, and of thoroughly acid character, also occur, and may be the fine-grained, cryptocrystalline, and glassy dyke-representatives of the magmas which gave rise to the northern and central granites.

Some large dykes of olivine-dolerite, dolerite, quartz-dolerite, craignurite (or 'porphyrite'), and felsite, are believed to have been injected at the same time as the great suite of quartz-dolerite–craignurite-felsite sills (Chapter XII); but the great majority of the dykes of this group were injected during the main dyke phase towards the end of the Kainozoic igneous activity. Almost invariably, where junctions are visible, the dykes of this group cut the dykes of the olivine-dolerite–crinanite group, thus repeating the sequence that occurred towards the beginning of the igneous period (p. 112).

Direction, Distribution, and Hade of the Dykes (Fig. 34).—It has been shown above (p. 238) that, on the whole, the Arran Swarm bends from a N.W to a N.N.W. direction as it passes through Arran. It follows that N.W. and N.N.W. are the most favoured directions for the dykes of the swarm, although other directions, notably north, are to be found. In order to establish the relative importance of the various dyke directions a statistical study of 525 dykes recorded on Gunn's six-inch maps was undertaken. These dykes are exposed across the entire width of the swarm on the east and south coasts of the island between North Sannox and Brown Head. In the majority of cases Gunn had recorded the thicknesses of the dykes. In order to determine the distribution of the dykes the region studied was divided into seven two-mile-wide N.W to S.E. strips, and the numbers, directions, and thicknesses of the east and south coast dykes were tabulated for each. The outline map (Fig. 34) shows the position of these strips, which are situated as follows :—

Strip I. Near Brown Head, to shore half a mile west of Bennan Head.
Strip II. Shore half a mile west of Bennan Head, to Port a' Bhuidh, Kildonan.
Strip III. Port a' Bhuidh, Kildonan, to Dippin Head.
Strip IV. Dippin Head, to mouth of Kingscross Burn.
Strip V. Mouth of Kingscross Burn, to Innean Beag, north side of Lamlash Bay.
Strip VI. Innean Beag, north side of Lamlash Bay, to Merkland Point.
Strip VII. Merkland Point, to Creag nam Maol, North Sannox.

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[1] *Mull Memoir*, 1924, p. 281.

[2] Tyrrell, *op. cit.*, p. 306.

[3] *Mull Memoir*, p. 282

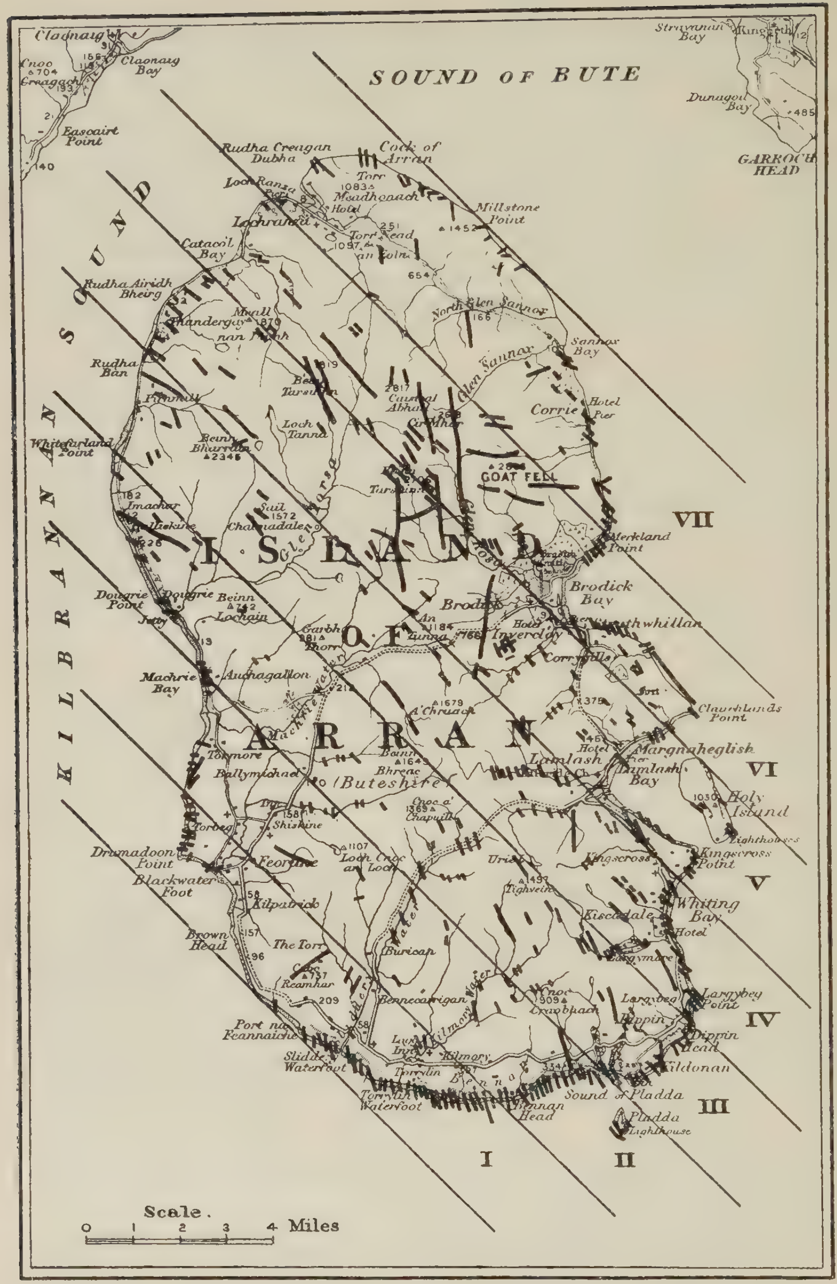

FIG. 34.—*Map showing distribution of the Arran Dyke Swarm, and the subdivision of the island into N.W.–S.E. strips* (see *p.* 241).

Each of these strips is two miles wide in the N.E. to S.W. direction, with the exception of Strip VII., which is 2·8 miles wide.

The dykes were tabulated as W.N.W., N.W., N.N.W., N., N.N.E., N.E., E.N.E., and E.; and a dyke was reckoned as belonging to one of these categories if its true direction was within 11¼ degrees on either side of the direction in question. The following table presents the results of the statistical study. For each direction the left hand part of the column gives the number of dykes in each strip, the right hand part their aggregate thickness.

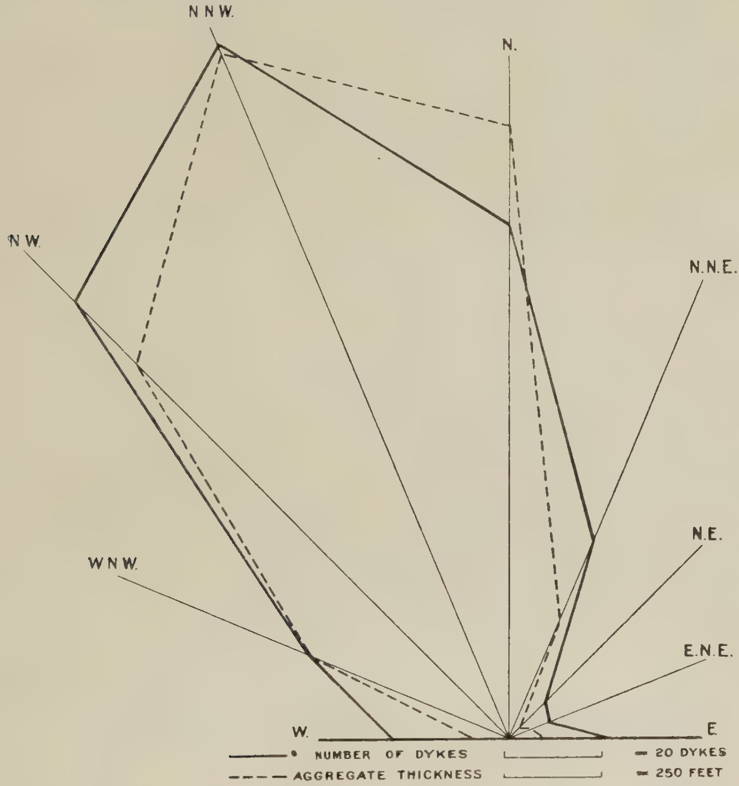

FIG. 35.—*Diagram illustrating relations between direction, number, and aggregate thickness of dykes in the Arran Swarm.*

The table shows that 393 dykes, or nearly 75 per cent. of the total number, run in the N.W., N.N.W., or N. directions; and that, of these three, N.N.W. is the most favoured direction. The predominance of dykes in these directions is shown still more strikingly by the fact that 81 per cent. of the aggregate thickness of the dykes occurs in them. The diagram, Fig. 35, graphically displays the distribution of the dykes according to direction. The numbers and aggregate thicknesses of the dykes in each direction are plotted along directional lines radiating from a centre. If the points thus

Strip No.	W.N.W.		N.W.		N.N.W.		N.		N.N.E.		N.E.		E.N.E.		E.		Total No.	Aggregate Thickness.	Average Thickness.
	No.	Ft.	No.	Ft.	No.	Ft.	No.	Ft.	No.	Ft.	No.	Ft.	No.	Ft.	No	Ft.	No.	Ft.	Ft.
I. ..	1	100	16	64	46	483	50	750	17	170	1	3	1	3	0	0	132	1573	11·9
II. ...	0	0	13	182	45	855	23	368	2	6	1	3	0	0	0	0	84	1414	16·9
III. ..	5	175	25	325	23	161	11	330	1	24	0	0	0	0	0	0	65	1015	15·6
IV. ..	17	187	37	407	5	30	0	0	2	5	0	0	0	0	8	28	69	657	9·5
V. ..	8	40	20	180	8	120	3	18	1	3	0	0	1	23	8	40	49	424	8·7
VI. ..	10	60	15	217	16	160	12	60	15	75	3	6	1	13	3	3	75	594	8·0
VII. ..	4	8	3	21	14	133	8	72	6	66	6	15	6	30	4	28	51	373	7·3
Total No.	45	—	129	—	157	—	107	—	44	—	11	—	9	—	23	—	525	—	—
Aggregate Thickness	—	570	—	1396	—	1942	—	1598	—	349	—	27	—	69	—	99	—	6050	—
Average Thickness	—	12·7	—	10·8	—	12·4	—	15·0	—	8·0	—	2·5	—	7·7	—	4·3	—	—	11·5

obtained are joined up, a characteristic figure is produced with its greatest elongation in the N.N.W. direction. The figure in thick, unbroken line represents the numbers, and that in broken line the aggregate thicknesses, of the dykes in the various directions. The shapes of the two figures are closely similar, and indicate strikingly the predominance of the N.N.W. direction, as well as the paucity of dykes in the N.E. and E.N.E directions. It is clear that the main direction of tension in the earth's crust over the Arran region during the Kainozoic igneous period was E.N.E. to W.S.W. Necker de Saussure's observations (*op. cit.*), while they indicate predominance of north and north-west dykes, nevertheless show relatively many more N.N.E. and N.E. dykes than the tabulation given above. This is probably because Necker de Saussure's observations were confined to the north-eastern and east central parts of Arran, where N., N.N.E., and N.E. dykes are relatively more abundant than in other parts of the island.

The division of the island into two-mile N.W. to S.W. strips according to the above-described scheme is somewhat arbitrary, but nevertheless brings out well the salient facts of the geographical distribution of the dykes. The table (p. 244) shows that the dykes congregate most thickly in I., the extreme south-western strip, and that the number of dykes gradually decreases towards the north-east, although there is an increase in their number in Strip VI., which includes the prolific Corrygills shore. The same progression is shown by the aggregate thicknesses of the dykes in the successive strips. The facts are further brought out by means of the diagram, Fig. 36, where the aggregate thickness of all dykes, and the aggregate thicknesses of dykes in the four principal directions, are plotted for each strip. The directional curves illustrate the interesting fact that the maximum aggregate thickness for each direction, as shown by the position of the summit of each curve, occurs in different strips. Thus northerly dykes reach their maximum aggregate thickness in Strip I., N.N.W. dykes in Strip II., N.W. and W.N.W. dykes in Strip IV. Apparently the effect of the flexure of the Arran Swarm towards the south is first experienced in the south-west of the island, so that the dykes in Strip I. are most sharply turned towards the N. to S. direction.

The above generalizations are based on the study of the very numerous dykes exposed along the eastern and southern shores of Arran, but it can be assumed with considerable probability, that they apply also to the equally numerous, but less well-exposed dykes of other parts of the coast and of the interior of the island. Nevertheless, there are many local variations from the general directional scheme. Attention has already been drawn to the dykes intruded into the northern granite (p. 162, and Plate III). They run in three main directions, approximately N.W. to S.E., N. to S., and E. to W., basalts (tholeiites) being predominant in the N.W. to S.E. direction, and felsites in the N. to S. direction. The rectangular system of dykes orientated N.N.W. to S.S.E., and W.S.W. to E.N.E. on Sgiath Bhàn, between Glen Dubh and Glen Ormidale, has also been previously noted (p. 202). Between Drumadoon Bay and Leacan Ruadha (Tormore), and also between Machrie Post Office (Cleiteadh Buidhe) and Dougrie, there is a great predominance of dykes approximating to an E. to W. direction. We may also note the relative paucity of dykes in the ring of Dalradian schists and Old Red Sandstone around the Northern Granite, and in the Central Ring Complex, which is certainly not due to lack of exposure.

It may be suggested that some of these variations in number and direction were due to accidental circumstances arising from the form, attitude, structure, degree of hardness, homogeneity or heterogeneity, and susceptibility to regular fracture and jointing, of the rocks into which the dykes were injected, whereby the general E.N.E. to W.S.W. tension was resolved into somewhat different directions, or failed, partially or entirely, to come into operation. Thus the heterogeneity of the rocks within the Central Ring Complex, and the structure and attitudes of the rocks surrounding the Northern Granite, with the consequent relative lack of uniformly-directed fractures, may account for the paucity of dykes in these areas. On the other hand, the uniformity of the northern granite, and its susceptibility to regularly-directed joint-

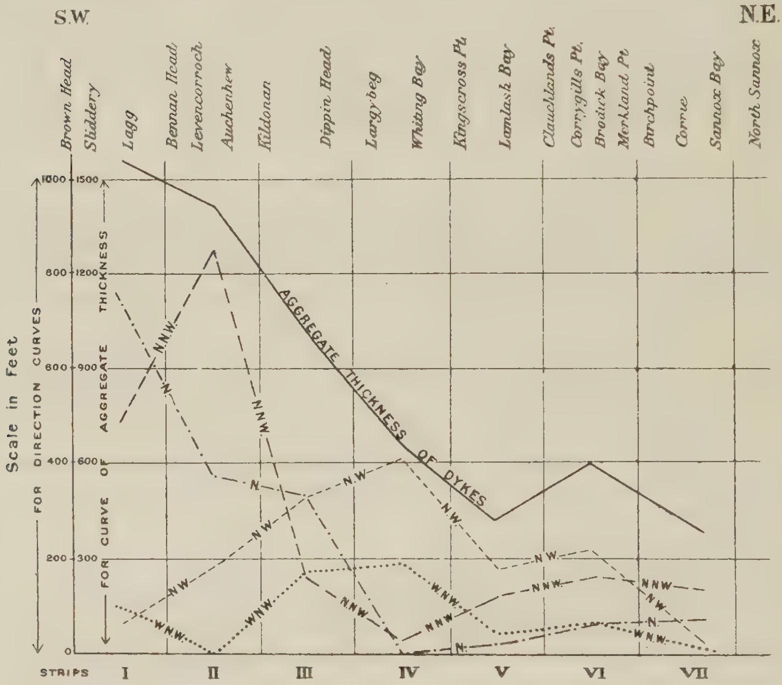

FIG. 36.—*Curves illustrating geographical distribution of dykes in the Arran Swarm* (*p.* 245).

ing, may explain the relative abundance of dykes in this country-rock. A similar explanation may be given of the extraordinary abundance of dykes penetrating the New Red Sandstones in the normal direction, as shown by the wonderful sections along the south coast of Arran (Plate V, 1).

The majority of the dykes in the Arran Swarm fill vertical or nearly vertical fissures, but where inclinations have been observed the dykes most often hade to the N.E. or E.N.E. at an angle of 60° to 70°. An especially good example of this inclination is to be observed in the 'Mile-dyke,' the long north-west dyke which is exposed between tide-marks on the Corrygills and Clauchlands shore.

G.W.T.

LENGTH, THICKNESS, AND AGGREGATE BULK OF DYKES IN THE ARRAN SWARM

The absolute lengths of the dykes can only be determined in a very few cases where they are seen to die out on the foreshore or in inland cliffs. Probably a good many of the small dykes, which are only visible in burn sections, have a very short course, at all events above ground. As regards others mapped for some distance, we can but say how far they have been traced. The large Imachar dyke can thus be said to have a course of about one mile, and the North Penrioch dyke can be traced for three-quarters of a mile. In the granite area west of Loch na Davie, a north-west running dyke has been followed over Beinn Bhreac for one and a quarter miles, and some W.N.W. dykes near Goatfell can be traced almost as far. One of the longest and most remarkable is that which forms the deep rift of Ceum na Caillich, east of Caisteal Abhail, crosses in a southerly direction the head of Glen Sannox, makes a gorge on the north side of the Saddle by no means easy to traverse, and runs for some distance down Glen Rosa, being altogether more than 2 miles in length. Probably it extends much farther in both directions; a dyke which appears in the bed of the Rosa Burn for some distance about three-quarters of a mile above the Garbh Allt being a probable continuation to the south. This dyke is 24 feet wide at Ceum na Caillich, 12 to 15 feet at the rift in The Saddle, and farther south in Glen Rosa about 10 feet.

W.G.

Two further examples of dykes which may be traced continuously for more than half a mile are the 'Mile-dyke' along the Corrygills–Clauchland shore, forming a conspicuous trench on the foreshore for the greater part of its course; and a N.N.W. dyke that intersects the Dippin crinanite sill, and runs parallel to its outcrop, in the district of Largymeanoch, 1½ miles south of Whiting Bay Pier (*see* Fig. 16).

The dykes vary greatly in width. The range is from less than a foot to at least 100 feet, which thickness is reached by the great quartz-dolerite dyke at Imachar on the west coast. There are, however, dyke-complexes, multiple, and composite dykes, whose aggregate thickness may be as great, or even greater, than this.

Examples are the composite dyke at Cleiteadh nan Sgarbh, north of Drumadoon (p. 200, Fig. 26); a composite dyke of felsite and basalt recorded by Gunn at Eilean Mairi, on the shore 1½ miles west of Bennan Head, which attains a maximum width of 200 feet; and a dyke-complex occurring on the shore a quarter of a mile east of Kildonan Castle, which consists of at least six members composed of different varieties of basalt, and aggregates about 150 feet in thickness. The following are single dykes of 50 feet or more in width: a N.N.E. dyke 60 feet thick on the shore north of An Cnap, North Sannox; a north-west dyke 70 feet thick on the shore opposite the Free Church, Kildonan; a N.N.W. dyke 50 feet thick on the Auchenhew shore, half a mile west of the Free Church, Kildonan; a north dyke 60 feet thick on the shore one-third of a mile north-east of the mouth of the Struey Water, Bennan Head; a N.N.W. dyke 70 feet thick on the shore 200 yards west of the Struey Water; another N.N.W. dyke 50 feet thick 200 yards west of the above; a W.N.W. dyke 100 feet thick on the shore near Torr nan Uain, one mile west of Bennan Head; and a W.N.W. crinanite dyke 50 feet thick at Rudha Bàn, three-quarters of a mile north of Pirnmill. Many other dykes have widths ranging between 20 and 50 feet.

Dykes of 20 feet or more in width almost invariably belong to the olivine-dolerite–crinanite group; and the larger ones are generally of the 'spotty crinanite' type which is believed to be of comparatively early date. The tholeiite dykes are in general thinner than the crinanites.[1]

Gunn was of the opinion that the majority of the Arran dykes were less than 10 feet wide.[2] That this was an underestimate is shown by the table (p. 244), in which the average thickness of Arran dykes, based on many hundreds of measurements, works out at 11·5 feet. The average thickness of the Mull dykes, as computed from 432 measurements, is 5·8 feet,[3] only half that of the Arran dykes. The average thickness of the 149 Arran dykes tabulated by Necker de Saussure (*op. cit.*) works out at 9 feet.

The table (p. 244) further shows that the north dykes are the thickest of the directional sets, and that the dykes in the directions west of north are considerably thicker than those in directions east of north. This is no doubt due to the fact that the thick crinanite and olivine-dolerite dykes tend to take north-westerly directions, whereas the thinner tholeiite dykes predominate in directions to the east of north. As regards geographical distribution the table shows that the average thickness of the dykes increases from Strip VII. to Strip II., *i.e.* from north-east to south-west across the island, but that in Strip I., the extreme south-western part, the average thickness again diminishes.

The aggregate thickness of the dykes exposed across the Arran

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[1] J. W. Gregory and G. W. Tyrrell, 'Excursion to Arran,' *Proc. Geol. Assoc.*, vol. xxxv., 1924, p. 406.

[2] 'The Geology of North Arran, etc.', (Explanation of Sheet 21), *Mem. Geol. Surv.*, 1903, p. 100.

[3] *Mull Memoir*, 1924, p. 360.

Swarm in Arran amounts to 6050 feet, if totalled without regard to the directions of the dykes. If the general direction of tension in the earth's crust over the Arran region, of which the dykes constitute evidence, be taken as E.N.E. to W.S.W., *i.e.* perpendicular to the most common dyke-direction, 6050 feet will be an overestimate for the amount of stretching the crust has undergone in this region owing to the intrusion of the dykes. Resolving the stretching in each case into the E.N.E.–W.S.W. direction, we obtain the following figures :—

		Ft.
Stretching perpendicular to	N.N.W., *i.e.* in E.N.E.–W.S.W. direction	1942
	N.W., resolved in E.N.E.–W.S.W. direction ..	1280
	N. ,, ,, ,, ..	1476
	W.N.W., ,, ,, ,, ..	433
	W., ,, ,, ,, ..	37
	N.N.E., ,, ,, ,, ..	232
	N.E., ,, ,, ,, ..	10
	E.N.E., ,, ,, ,, ..	—
	Total	5410

Thus the total stretching of the earth's crust in the E.N.E.–W.S.W. direction amounts to 5410 feet, a little over a mile. This elongation has taken place over a belt of country 14·8 miles wide. Hence over the Arran region there is one mile of elongation in the E.N.E.–W.S.W. direction for 14·4 miles of crust. The comparable figures for the Mull Swarm are 2504 feet of stretching in 12·5 miles,[1] or one mile of elongation in about 26·4 miles of crust. Hence the intrusion of the Arran Swarm has necessitated about twice as much stretching of the crust as the Mull Swarm.

AGE OF THE DYKES

The relative ages of the dykes with respect to the other age or petrographical groups of Kainozoic igneous rocks in Arran, and the relations of the dykes amongst themselves, are perplexing problems. While it is certain that the majority of the dykes in the swarm belong to a late stage of igneous activity, yet unquestionably there were dykes associated with each of the earlier stages. A recurrence of identical types, at least once, makes the question even more difficult. The dykes of the Arran Swarm may be found cutting the crinanite sills, the quartz-dolerite–craignurite–felsite composite sills, the northern granite, the Central Ring Complex, and quartz-porphyries and associated rocks. They are, however, very rarely found intersecting the compact felsite sills or dykes. While this may be due in some cases (*e.g.* Holy Island) to the fact that some of the acidic intrusions are later than the dykes, in at least two cases (Corrygills, p. 213, and Blackwaterfoot, p. 221) it is due to a curious reluctance of the dykes to penetrate the very compact unfissured felsites and their contact rocks. Hence some, at least, of the Arran dykes are later than the late felsites.

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[1] *Mull Memoir*, 1924, p. 360.

Another fact which shows that some of the tholeiite dykes are of later date than certain members of the pitchstone-felsite group is that xenoliths of pitchstone have been found within the tholeiite dyke that cuts the Dippin crinanite at the roadside quarry near the twelfth milestone, on the main road at Dippin.[1]

Not a single dyke unequivocally belonging to the olivine-dolerite–crinanite set has been found within the northern granite. Most of the dykes intersecting the granite belong to the tholeiite group, and are of the Corrie and Brunton types. There are also many examples of a coarse, porphyritic dolerite, frequently with a little olivine (as, *e.g.*, the long north to south dyke that crosses The Saddle, Glen Rosa). These rocks are merely coarse-grained basic tholeiites, as is shown by their profusely porphyritic character, and by the presence of the zoned mechanical inclusions within the felspars that are so characteristic of the rocks of the tholeiite group, especially the olivine-bearing, porphyritic, Corrie type. Exactly similar types are represented by the basic dykes that cut the Central Ring Complex, and no definitely crinanitic dykes have been found within the boundaries of this structure.

On the other hand, as has been previously mentioned (p. 158), some dyke rocks have clearly been metamorphosed by the granite. An example which has been sliced is that of a dyke occurring in the Cnocan Burn below the Mill Dam (7442). The slice shows a contact between a coarse granophyric vein and an altered dolerite (described on p. 158). Despite the alteration the general aspect of the slice strongly suggests that the original rock belonged to the olivine-dolerite–crinanite group. The evidence, tenuous as it is, nevertheless suggests that some dykes of the olivine-dolerite–crinanite group pre-dated the granite, whereas many dykes of the tholeiite group clearly post-dated the granite. No explanation, however, can be yet offered of the fact that none of the later crinanites (p. 240), which were closely associated with the tholeiites in the main period of intrusion of the Arran Swarm, are to be found in the granite. The centre of distribution of these dykes, as far as present information goes, seems to lie in the south, and especially in the south-east, of Arran.

The study of the Survey collection of slices of the dyke-rocks has brought to light the interesting and important fact that a dyke of porphyritic basalt (9420), labelled : 'Dyke in Glen Cloy between Creag na h' Iolaire and Creag nam Fitheach,' and thus collected within the aureole of altered rocks surrounding the Central Ring Complex, has clearly shared the propylitization, the soaking with epidote, etc., which these rocks have undergone. Otherwise it is a typical member of the group of the porphyritic basalts (p. 240). Hence some of these dykes must have pre-dated the Central Ring Complex.

As regards interrelations between the dykes themselves it has been found that in all the observed intersections, dykes of the tholeiitic group cut those of the olivine-dolerite–crinanite group, or other tholeiites. A noteworthy case occurs on the shore opposite Breadalbane House, Kildonan,[1] where a tholeiite dyke with a tachylytic margin intersects a coarse, decomposed olivine-dolerite of the crinanite affiliation. In this late magmatic recurrence the evidence thus clearly points to the same succession of undersaturated by oversaturated magma as was observed between the crinanite sills and the sills of the quartz-dolerite series (p. 117).

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[1] G. W. Tyrrell, 'The Petrography of Arran,' III., *Geol. Mag.*, vol. liii., 1916, pp. 193–196.

PETROGRAPHY

A sketch of the broader petrographical features of the Arran dykes has already been given (p. 239). Unfortunately these rocks are only sparingly represented in the Survey collection. The crinanite type is represented by two specimens, that of a dyke forming a roadside crag above Cordon, Lamlash (25052), and the first-described Arran crinanite from the shore near the Schoolhouse, Whiting Bay (26383). In thin section these rocks consist of an ophitic plexus of labradorite laths and deep-purple augite, with abundant olivine (mostly serpentinized) and ilmenite. Fresh analcite occupies many of the interspaces between these constituents. An analysis of the Whiting Bay rock is given and discussed later (Table I., 3 ; and Table IX., 3).

Porphyritic basalts with phenocrysts of felspar are represented by four specimens. Two of them, at any rate, probably represent, in Arran, those dykes of ‘ porphyritic central-lava ’ type which have been described from Mull,[2] the petrographical characters of which are very similar. A dyke from Glen Dubh (14199) shows large glomeroporphyritic aggregates of basic plagioclase (approaching bytownite in composition) with a curious micaceous alteration, in an intergranular groundmass consisting of plagioclase laths (labradorite), colourless augite, a little serpentinized olivine, and iron-ores. A somewhat similar rock, with a dense decomposed groundmass, and interspersed with epidote in veins and patches, is that of a dyke from between Creag na h’ Iolaire and Creag nan Fitheach at the head of Glen Dubh (9420), which has already been mentioned (p. 250). A different type is represented by a dyke from east of Rinn a’ Chrubain, Corriecravie (6364). This shows sparse phenocrysts of basic plagioclase in an ophitic groundmass of plagioclase laths and purple augite, with abundant serpentinized olivine. A beautifully fresh rock of the same character, but with smaller and more abundant porphyritic felspars, comes from a dyke by the roadside a twelfth of a mile north of Birchpoint, 1¾ miles south of Corrie (25057). The two last-named rocks may be merely coarse-grained porphyritic representatives of tholeiites of Corrie and Salen types (*see* later).

The remaining sliced dyke-rocks in the Survey collection are of tholeiitic characters (p. 240). While typical tholeiites in the restricted sense (*i.e.* non-porphyritic) [3] are abundant in Arran, other types with phenocrysts of basic labradorite, and occasionally of augite, are also abundant. With increasing coarseness of grain and the approach of holocrystallinity, the more basic types of tholeiite tend to pass into ophitic olivine-bearing dolerites which are sometimes not easily distinguishable from rocks belonging to the crinanite–olivine-dolerite group. The more acid types of tholeiite tend to pass into quartz-dolerites and craignurites indistinguishable from the more fine-grained rocks of the quartz-dolerite sills.

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[1] Figured in *Proc. Geol. Assoc.*, vol. xxxv., part iv., 1924, p. 417.

[2] *Mull Memoir*, 1924, p. 369.

[3] *Mull Memoir*, 1924, p. 280.

The most basic types of tholeiite in Arran are the olivine-rich rocks which have been distinguished as the Largs type.[1] A dyke of this character occurs in the gorge known as Creag Bhan in the Allt Mòr, Whiting Bay (25077). In thin section this rock contains numerous microphenocrysts of labradorite and fresh olivine, sometimes aggregated into glomeroporphyritic groups, in a groundmass consisting of plagioclase laths, augite plates, skeletal iron-ore, and partially devitrified brown glass. An analysis of this rock is given in Table IX., 19, below. An extraordinary rock which probably forms an extreme member of this group occurs as a thin dyke in the schists west of Creag Rosa, Glen Rosa (9405). It shows very numerous, large, euhedral phenocrysts of olivine, mostly serpentinized, in a groundmass of brown glass the only crystalline elements of which are microlites of plagioclase.

The olivine-tholeiites of Salen type common in Mull[2] are unrepresented in Arran, unless it is by a dyke in Glen Rosa at the junction of the Rosa Water with a tributary from Goatfell, half a mile south of The Saddle (25045). This rock is a coarse ophitic aggregate of labradorite and pale augite, with a little serpentinized olivine, and some dark, green-stained, mesostasis which, at one place, is aggregated into a fine-grained vein. A somewhat similar rock forms the basic member of Judd's No. III. composite pitchstone-basalt dyke on the Tormore shore (25625).

Olivine-bearing tholeiites which carry phenocrysts of basic plagioclase are rather common in Arran, and have been designated as the Corrie type.[3] An analysed (Table IX., 20), and figured example[4] is the rock of a N.N.E. dyke on the shore a quarter of a mile north of Birchpoint, and $1\frac{3}{4}$ miles south of Corrie Hotel (26384). This rock carries numerous small phenocrysts of bytownite-anorthite, often corroded into curiously irregular shapes, and enclosing glassy particles in a thick marginal zone which faithfully follows the fantastic outlines of the crystals. The groundmass consists of laths of labradorite (Ab_1An_1) intermingled with granular or short prismatic crystals of a pale augite which is the most abundant constituent. Minute grains of olivine, partially or wholly serpentinized, with euhedral magnetite crystals, are uniformly scattered over the field. The interstices are occupied by a colourless glass containing numerous black globulites ; and small spherical vesicles are filled with the same material.

Another good example of the Corrie type is the east to west dyke along the gully by which the descent of The Saddle into Glen Sannox is made (25070). The glass-filled vesicles in this rock are surrounded by concentric felspar laths, producing an ocellar structure.

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[1] G. W. Tyrrell, 'Some Tertiary Dykes of the Clyde Area,' *Geol. Mag.*, 1917, p. 353.

[2] *Mull Memoir*, 1924, pp. 285, 370.

[3] Tyrrell, *op. cit.*, *supra*, p. 352.

[4] *Ibid.*, p. 351, and *Trans. Geol. Soc. Glasgow*, vol. xiii., part iii., 1909, Plate XIX., Fig. 5.

The olivine-free Brunton type of tholeiite[1] is unrepresented amongst the Survey collection of Arran rocks, although it occurs frequently in the Arran Swarm. But a type carrying microphenocrysts of basic plagioclase, augite, and occasionally orthopyroxenes, with a Brunton type of groundmass in which the glassy mesostasis or its devitrified equivalent is more abundant than in the typical Brunton tholeiites, is quite common in Arran, and is represented by several specimens in the Survey collection. Rocks of this type especially rich in glass have been described as the Cumbrae type of tholeiite or *cumbraite*.[2]

The analysed rock of this type (25622) is the basic member of Judd's No. II. pitchstone–tholeiite composite dyke on the Tormore shore (p. 220). The mesostasis is devitrified with the production of quartz, alkali-felspar, and chloritic substances, and there are a few xenocrysts of quartz with coronas of granular augite, and turbid corroded crystals of andesine which may represent material obtained from a pitchstone or quartz-porphyry magma.

The basic member of the Cir Mhòr composite dyke (25073, 25619) is an even more typical example of this group as it is devoid of xenocrystic material. It shows excellent examples of magma-invaded vesicles, as does also the Tormore rock. An old analysis of this rock is quoted in Table IX., 22.

The rock of the dyke which cuts the Dippin crinanite in the quarry on the roadside at the twelfth milestone near Dippin (6362) belongs to the above-described group, but is richer in mesostasis than the Tormore or Cir Mhòr examples. It contains bytownite, augite, and enstatite, named in order of abundance, as phenocrysts. It is a comparatively coarse, devitrified member of the Cumbrae group of tholeiitic rocks, and in the field it has been found to contain xenoliths of pitchstone.[3]

A rock of the same mineralogical composition as the above, but in which the felspar and augite form elongated prismatic crystals in an abundant, partially devitrified groundmass, comes from Traghariabhach, a little south of the twelfth milestone at Dippin (6880), and is an excellent example of the Talaidh type of tholeiite.[4]

Finally we may mention the tachylyte which is frequently found on the margins of the tholeiite dykes, and occasionally forms the whole of a thin dyke. Two good examples of tachylyte dykes, respectively 12 inches and 18 inches thick, occur in the Allt an Bhrighide, five-eighths of a mile W.N.W. of West Glenshurig, Glen Shurig. The thinner dyke has been sectioned (24371), and shows a dark, almost opaque glass, containing a few needles and microporphyritic crystals of labradorite. In places the glass is less opaque, and then shows an obscure variolitic structure of minute felspar needles.

Another tachylyte forms a thin sill-like mass intersecting the western part of the great dyke-complex on the shore a quarter of a mile west of Kildonan Castle (25058). The dark glass is charged with acicular microlites of felspar and opaque globulites, and envelops numerous small crystals of labradorite and colourless augite.

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[1] *Mull Memoir*, 1924, pp. 285, 372.

[2] Tyrrell, *op. cit. supra*, p. 306.

[3] G. W. Tyrrell, 'The Petrography of Arran,' *Geol. Mag.*, 1916, pp. 193–196.

[4] *Mull Memoir*, 1924, pp. 284, 372.

CHEMICAL COMPOSITION

One analysis of a crinanite dyke, and three of tholeiitic dykes, are now available, and are set out in Table IX. below.

TABLE IX

	3.	19.	19A.	X.	20.	Y.	Z.	21.	13.
SiO_2 ..	43·95	42·55	46·6	47·35	48·60	47·24	51·53	54·52	55·79
Al_2O_3 ..	17·60	16·93	18·6	13·90	18·27	18·55	11·05	14·53	15·97
Fe_2O_3 ..	1·43	3·43	3·8	5·87	3·19	6·02	2·73	2·21	12·50
FeO ..	11·89	6·81	7·5	8·96	7·17	4·06	10·98	6·06	—
MgO ..	6·95	6·05	6·7	5·97	6·29	5·24	5·21	5·61	2·22
CaO ..	8·54	12·64	8·5	10·65	10·15	11·72	9·68	8·08	7·06
Na_2O ..	3·66	2·18	2·4	2·73	1·63	2·42	3·48	3·66	2·21
K_2O ..	·35	·32	·4	·54	·45	·15	·86	1·14	1·86
$H_2O > 105°$	·82	1·30	1·4	1·16	1·65	2·24	1·26	·93	2·43
$H_2O < 105°$	·94	1·78	1·9	1·04	1·60	·21	·71	1·95	—
TiO_2 ..	3·42	1·80	1·9	1·75	·70	1·46	1·57	·87	—
P_2O_5 ..	·11	·11	·1	·24	·09	·26	·22	·21	—
MnO ..	·10	·12	·1	·23	·24	·31	·45	·24	—
CO_2 ..	nt. fd.	3·85	—	·32	nil	·19	·08	—	—
FeS_2 ..	—	—	—	—	—	nt. fd.	·26	—	—
S ..	tr.	·13	·1	·23	tr.	—	—	—	·45
BaO ..	—	—	—	—	—	nt. fd.	nt. fd.	·03	—
Li_2O ..	—	—	—	—	—	nt. fd.	—	nt. fd.	—
(Ni,Co) O	nt. fd.	nil	—	nt. fd.	nil	·05	nt. fd.	nt. fd.	—
	99·76	100·00	100·0	100·94	100·03	100·12	100·07	100·04	100·49

3. (26383) Crinanite, dyke on shore near Schoolhouse, Whiting Bay, Arran. *Anal.* W. H. Herdsman. Quoted from *Trans. Geol. Soc. Glasgow*, vol. xviii., part ii. (in the press).

19. Olivine-tholeiite (Largs type), dyke, Creag Bhàn, Allt Mòr, Whiting Bay, Arran. *Anal.* W. H. Herdsman. Quoted from *Trans. Geol. Soc. Glasgow*, vol. xviii., part ii. (in the press).

19A. The same, freed from $CaCO_3$, and recalculated to 100.

X. (16808. Lab. No. 407.) Olivine-tholeiite (Salen type), dyke, shore, quarter of a mile S.S.E. of Kintallen, and 2½ miles N.N.W. of Salen, Mull. *Anal.* F. R. Ennos. Quoted from *Mull Memoir*, 1924, p. 17.

20. (26384) Olivine-tholeiite (Corrie type), dyke, shore, quarter of a mile north of Birchpoint, 1¾ miles south of Corrie Hotel. *Anal.* W. H. Herdsman. Quoted from *Trans. Geol. Soc. Glasgow*, vol. xviii., part ii. (in the press).

Y. (18469, Lab. No. 445.) Basalt lava, porphyritic central type, half a mile S.S.W. of Derrynaculen, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir*, 1924, p. 24.

Z. (16810. Lab. No. 406.) Tholeiite (Brunton type), dyke, shore, quarter of a mile east of Arla, 5½ miles south-east of Tobermory, Mull. *Anal.* E. G. Radley. Quoted from *Mull Memoir*, 1924, p. 17.

21. (25622. Lab. No. 853). Tholeiite (cf. Brunton type), basic member of composite pitchstone-tholeiite dyke, Judd's No. II. dyke (Fig. 30, p. 219), Tormore shore, Arran. *Anal.* E. G. Radley.

13. Tholeiite (cf. Brunton type), basic member of composite pitchstone-tholeiite dyke, Cir Mhòr, Arran. *Anal.* J. A. Schofield. Quoted from J. W. Judd, 'Composite Dykes of Arran,' *Quart. Journ. Geol. Soc.*, vol. 49, 1893, p. 545. Repeated from Table VI.

The analysis of the crinanite dyke from Whiting Bay has already been commented on (p. 122), and its close resemblance to that of the Dippin crinanite noted. It is remarkable for high alkalies, especially soda, in association with relatively low silica. The total (FeMg)O is very high, indicating abundance of olivine, and the analysis shows the highest amount of TiO_2 (3·42 per cent.) so far recorded in an Arran rock.

The specimen of olivine-tholeiite (Largs type) from Creag Bhàn, Whiting Bay, which was selected for analysis, unfortunately contained a large amount of calcite in vesicles. When, however, the $CaCO_3$ content of the analysis is deducted, and the remaining figures recalculated to 100, the result (Table IX., 19A) exhibits the close relationship of this type to the olivine-tholeiite of Salen type from Mull (Table IX., X), and also to the other type of olivine-tholeiite from Corrie (Table IX., 20). The Arran rocks differ chiefly from the Mull type in containing a larger amount of Al_2O_3, indicating a higher proportion of felspar. While all of these three types of tholeiitic rocks contain modal olivine, they can, on calculation of the norms, be shown to possess a slight excess of silica, and are therefore magmatically over-saturated. The affinities of the olivine-tholeiites, especially the Largs and Salen types, are with the Staffa types amongst the basalt lavas of the Western Isles, and with the non-porphyritic central-basalt magma-type of Mull in general, as is shown by the close similarity of their analyses.[1] On the other hand, the Corrie type (Table IX., 20) shows a certain likeness to the porphyritic central-magma type of Mull, and an analysis of a lava of this type is given for comparison (Table IX., Y).

The remaining analysis, that of the tholeiite from the Tormore shore (Table IX., 21), is distinctly more acid than any of the foregoing. Notwithstanding its somewhat higher silica, which may be partly due to the presence of xenocrysts of quartz, its closest affinities amongst true tholeiites, are with the Brunton type of Mull, an analysis of which is given for comparison (Table IX., Z), and with the Talaidh type, also of Mull.[2]

Defective and incomplete as it is, the analysis of the tholeiite member of the pitchstone-tholeiite composite dyke of Cir Mhòr (Table IX., 13), given by Judd, nevertheless betrays its likeness to the Tormore rock. Another Arran rock of comparable composition is the hypersthene-dolerite of Bennan Head (Table VI., 12). This rock bears the same field-relation to quartz-porphyry (p. 196) as do the Tormore and Cir Mhòr tholeiites to pitchstone. The analysis of the quartz-dolerite of the Allt Dhepin is again not markedly different from that of the Tormore rock (Table II., 4). G.W.T.

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[1] *Mull Memoir*, 1924, p. 17. See also remark concerning the tholeiitic characters of the Staffa basalt type (p. 146).

[2] *Mull Memoir*, 1924, p. 17.

CHAPTER XVII

POST-IGNEOUS, GLACIAL, AND POST-GLACIAL GEOLOGY OF ARRAN

POST-IGNEOUS AND PRE-GLACIAL GEOLOGY

So far as is known there are no deposits in Arran belonging to the period intervening between the close of the Kainozoic igneous episode and the beginning of the glacial epoch of the Pleistocene. The only guides to the geological history of this time are the major topographical features which were initiated during this interval. That the origin of the present topographical features of Arran long post-dated the end of the igneous episode is shown by the way the valleys cut the later dykes. If the valleys had been in existence towards the end of the igneous period lava would have been poured out into them. Similarly the major topographical features predated the Pleistocene glaciation, as can be shown by the distribution of the glacial deposits and striæ.

There can be no doubt but that at the close of the igneous period Arran formed part of an elevated plateau which included most of Scotland. This plateau extended far to the north-west, and had a gentle inclination to the south-east. From it the existing Highland topography has been developed mainly by river erosion. According to Prof. J. W. Gregory, North Arran probably presented the appearance of a gently-undulating tableland 2000 feet or more above sea-level, and at this stage some consequent valleys, such as the Glen Chalmadale–North Sannox 'through' valley, may have been incised on its surface.

The Thousand-foot Platform.—From many viewpoints the northern granite mountains are seen to be surrounded by a well-marked rock platform, at heights of from 800 to 1200 feet. The well-known view of Goatfell from Brodick Bay (Plate I, *Frontispiece*) shows a remarkable development of this feature on both sides of Glen Rosa. Another viewpoint from which the platform can be well seen is Windmill Hill, near the summit of the String Road. Other fine developments of the platform are to be seen on the west side of the mountains south of Pirnmill, and between Glen Catacol and Glen Easan Biorach. This feature has been closely studied by Dr. F. Mort [1] and by Prof. J. W. Gregory.[2] According to the latter author the platform varies in height from 800 to 1200 feet around Goatfell and north-west of Brodick, 700 to 1000 feet alongside the western coast from lower Glen Iorsa to Pirnmill, and from 750 to 1000 feet north of North Glen Sannox. Its width averages about one mile. It slopes imperceptibly upwards from its outer margin, and ends off abruptly against the steep sides of the mountains.

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[1] 'The Sculpture of the Goatfell Mountains,' *Scottish Geogr. Mag.*, vol. xxvii., 1911, pp. 632–643; 'The Sculpture of North Arran,' *ibid.*, vol. xxx., 1914, pp. 393–404; 'North Arran: A Physiographic Study,' Thesis for D.Sc., University of Glasgow, 72 pp., 1914.

[2] 'The Pre-Glacial Valleys of Arran and Snowdon,' *Geol. Mag.*, vol. lvii., 1920, pp. 148–164.

The platform can be recognized at a lower altitude in the southern part of the island, although it is not so conspicuous as in the region adjacent to the mountains. Prof. Gregory states that its height varies from 500 to 750 feet in the south-western part between Blackwaterfoot and Glenscorrodale, and from 500 or 600 to 900 feet in the south-eastern part of the island. The uplift that produced the platform must, therefore, have been differential, with the greatest amount of uplift north of Brodick.

Around the granite mountains the platform is everywhere quite independent of the nature of the underlying rock formation. It is eroded on schist and granite indifferently. Its drainage is remarkably immature, and the surface is practically untrenched by stream erosion.

The age of this feature is certainly pre-Glacial, for its surface is plastered with drift, and deep valleys with glaciated floors on which are well-preserved moraines, have been cut through it. The 'thousand-foot platform' of Arran is correlated both by Dr. F. Mort and Prof. J. W. Gregory with the Pliocene plateau, of which remnants are widespread throughout Great Britain, and which is especially clear in North Wales and Cornwall.

Dr. F. Mort advances good reasons for regarding the 'thousand-foot platform' as due to marine erosion, in which opinion Prof. Gregory concurs. If this is so, it is evidence of an uplift of at least 1000 feet, probably much more if the buried valleys of south-western Scotland are taken into account.

Fragments of a lower platform at 400 to 500 feet above sea-level can occasionally be detected, as Dr. Mort points out. One of the best examples of this erosion plane is the platform which rises immediately west of Corrie. Inland from Lamlash and Whiting Bay there are also traces of a platform at about this level.

The Valley System of Arran.—A radial system of valleys, diverging approximately from the centre of the granite mass, is discernible in North Arran (p. 3), but as Prof. Gregory has shown,[1] this system is subordinate to a major system of three 'through' valleys which run roughly north and south. It may, however, be pointed out that the main direction of the Catacol–Scaftigill, and the Easan Biorach–Iorsa valleys is N.N.E. to S.S.W., whilst that of the upper part of Glen Rosa runs approximately N.N.W. to S.S.E. The Catacol–Scaftigill depression has been guided by a shatter-belt or zone of crushed granite which was first pointed out by Mr. John Smith [2] (Plate III), while the Glen Rosa valley coincides with the direction and outcrop of one of the longest basalt dykes intersecting the granite. The line of the Glen Rosa valley is continued south-eastward over the col through which the Brodick–Lamlash road passes, and by the channel between Holy Island and Kingscross, as is well shown by the view up Glen Rosa the traveller gets when sailing from Whiting Bay to Lamlash on a clear day (cf. Plate VI). The Chalmadale–North Sannox valley to the north-east, which, as Dr. Mort suggests, was probably cut by a consequent river at an early stage in the physiographic history of the island, seems to have been guided to some extent by the important zone of fracture which bounds the granite on its north-eastern side, and which is continued to the north-west by the fiord inlet of Loch Ranza. As Dr. A. Scott mentions,[1] the only large valleys in the northern part of the island which do not conform to the approximate north to south trend are Glen Sannox, and the White Water south of Corrie, which, apart from the middle course of the Sannox (south-west to north-east), run roughly west to east. It may be pointed out that the lower part of Glen Catacol runs south-east to north-west. Hence valleys in the northern half of Arran tend to run parallel to the major tectonic directions which have been impressed upon the granite and its surrounding rocks, and to be guided by the zones of weakness which have been produced by the tectonic conditions.

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[1] *Op. cit.*, p. 150.

[2] *Trans. Geol. Soc. Glasgow*, vol. x., part ii., 1896, pp. 228, 254, and Plate V.

A survey of the chief valleys of the southern half of Arran yields the following facts as to their average directions. The only valley that runs approximately E.N.E. to W.S.W. is the ‘ through ’ valley of Glen Shurig—Gleann an t-Suidhe. Valleys running north-east to south-west include the Machrie Burn, the middle course of the Machrie Water and its tributary the western Garbh Allt, the Black Water, the Sliddery Water, the Kilmory Water, and the Glen Cloy–Glen Dubh valley. From east to west run the valleys of the lower part of Glen Iorsa, Auchencar Burn, the lower part of the Machrie Water, Ballymichael Glen, Clauchan Glen, Glen Ashdale, Kingscross Burn, Monamore Glen, Benlister Burn, and Glen Ormidale. The north-west to south-east valleys are Glen Craigag, Allt Dhepin, Sguiler Burn, and Blairmore Glen north of Lamlash. The north to south valleys are comparatively insignificant, and include only the Levencorroch Burn, the Allt Mòr and other streams near Kildonan, and the Strathwhillan Burn south of Brodick.

From this it appears that the pattern of the southern valleys, with the exception of the E.N.E. to W.S.W. ‘ through ’ valley of Glen Shurig—Gleann an t-Suidhe, conforms roughly to the main structural and tectonic directions of the island, although the north to south element so prominent in the north is reduced to insignificance in the south. Dr. A. Scott regards the south-westerly valleys, such as those of the Sliddery and Kilmory waters, as normal consequent streams flowing down the dip slope of the New Red Sandstone sediments.[2] The Benlister Burn (west to east) is regarded by him as an obsequent stream which has cut through the original watershed, and has diverted part of the headwaters of the Clauchan Burn.[3]

The north-west to south-east element in the pattern is due to the prevalence of dykes in that direction. Glen Craigag, the chief head-

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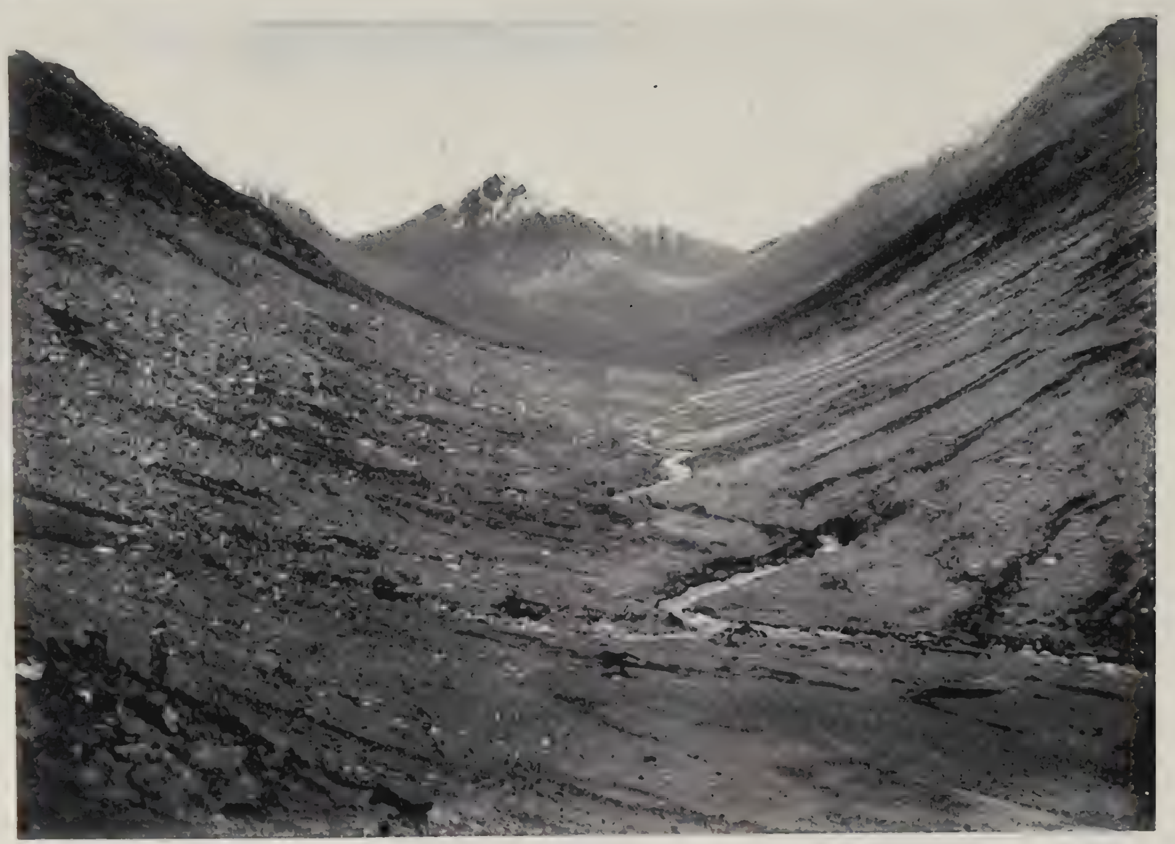
[1] ‘ Notes on the Physiography of Arran,’ *Scottish Geogr. Mag.*, vol. xxxiv., 1918, pp. 90–99.

[2] *Op. cit.*, p. 97.

[3] *Op cit.*, p. 98.



U-shaped valley of Glen Rosa, looking north ; Cir Mhòr at head of valley, and Ceum na Caillich (or Witch's Step) seen over the divide of The Saddle.

water of Benlister Burn, the Sguiler Burn, the upper part of the Allt Dhepin, and the scarp feature of Cnoc na Garbad (p. 132), are all practically on a straight north-west to south-east line nearly 10 miles in length, and over the greater part of that distance the north-west to south-east dykes can be shown to determine the directions of the valleys.

Sequence of Events in Post-Igneous and Pre-Glacial Times.—The system of tectonic fractures which traverses the northern half of Arran was certainly initiated before the close of the Kainozoic igneous period, for the later dykes were injected into many of the planes of weakness then produced. We may assume that at the end of the igneous episode, before the northern granite had been uncovered, Arran was joined to the mainland, and formed part of the Kainozoic plateau of Scotland from which the present topographical features of the country have been developed. Following Professor Gregory, we believe that Arran was first planed down to a gently-undulating plateau which stood 2000 to 3000 feet above sea-level, and was trenched by one, or perhaps two, of the early consequent north-west to south-east rivers. The relics of these valleys are the Chalmadale–North Sannox 'through' valley, which may have been influenced by the system of fractures on the north-eastern margin of the granite ; and the Glen Rosa–Blairmore Burn–Lamlash Bay depression, which may have been continued north-eastward along the line of Glen Catacol. This valley coincides in part with a long basalt dyke.

After the establishment of this system the country was again elevated, with the reopening of the north to south clefts across the granite, and the production of great tectonic valleys to east and west, isolating Arran from the mainland. The land must then have remained stationary for a period long enough for the formation of a low plain of marine erosion, which was raised by a third movement into the 'thousand-foot platform.' The tectonic clefts were again caused to gape, and were enlarged by denudation until their floors were but little above sea-level. Thus were produced the main north to south valleys across North Arran, although the writer believes that the Glen Rosa–Lamlash Bay depression was initiated at an earlier date than the other two, and was originally a part of the consequent drainage. During these movements the climate had gradually become colder, leading up to the Glacial Period which now supervened.

G.W.T.

Glacial Geology

Glaciation.—At the climax of the Pleistocene Glacial Period the Clyde region was covered by an ice-sheet which moved generally from north to south. This is evident not only from the distribution of erratic boulders in various parts of the district, but more particularly from a study of the glacial striæ on the solid rocks. The direction of these is almost due south in many examples on either side of the Little Cumbrae and near Ardscalpsie in Bute. Sometimes there is a deviation towards the east as on the rock called Miller's Thumb in Millport Harbour, where the direction is about 15° E. of S., and near Barr Buidhe, South Bute, where it is S.S.E. In other cases it is west of south, as in Bute to the east of Barefield (S.S.W.). It is clear, then, that the ice-sheet from the north moved over the comparatively low ground of Bute and the Cumbraes without let or hindrance, but the high hills of Arran divided the stream of ice as a rock in a running stream divides its current. For along the western side of the high ground south of Catacol we find almost universally the direction of the striæ parallel to the edge of the granitic mass. At first the direction is nearly S.W., as near Lochan a' Mhill. From Penrioch to Imachar the general trend of the ice-markings gradually changes from S.S.W. to almost due south, and about Balliekine it becomes east of south. Thus we have clear evidence that the ice-sheet *coasted* the high ground instead of going over it. The striæ on the granite inland to the west of the Iorsa valley have the same southerly tendency, but as the direction of these coincides with that of the valleys there it is not clear whether they are due to the great ice-sheet or to local glaciation. Portions of the great sheet may have gone over the watersheds at the heads of Catacol Burn and Easan Biorach, which are both under 1200 feet in height, and been augmented by local ice shed from the neighbouring hills.

The larger granitic mass east of the Iorsa caused a much greater deviation in the direction of the ice-sheet, for from Torr Meadhonach, in the north of the island, all along the skirts of the mountains we find the general direction of glaciation to have been between E.S.E. and due east. This continues at least as far as Farchan Mòr on the south side of Glen Sannox. It now becomes pretty clear that the high mountains of Arran were not overridden by the general ice-sheet, but they must, both before and at the time of greatest glaciation, have been covered by a local ice-cap which shed material all round to increase the general mass of ice. The high ground south of Gleann an t-Suidhe may have formed a local ice-sheet also. At all events we have evidence that to the south of this the general ice-sheet moved south-westward over Arran towards Kintyre. It may be mentioned that glacial striæ are particularly numerous and good on the west side of Arran near the road between Whitefarland and Imachar; a particularly fine example of a grooved and polished surface of schist may be observed by the roadside at the former place.

To the east-south-east of Auchencar ridges of drift or drumlins which are parallel to the general direction of the glacial striæ are very prominent. They trend somewhat to the west of south, and in several cases are evidently examples of the phenomenon called crag and tail, for each of them is under the lee of a crag behind which the glacial material has accumulated. W.G.

In his uncompleted MS. on Sheet 13 Gunn listed some notable localities for well-preserved glacial striæ in the southern part of Arran as follows :—

Striæ are most numerous and best preserved on the quartz-porphyry of Brown Head and Cnocan Doun. They all run nearly N.N.W. A hundred yards east of Ballymeanochglen west of Dippin there is a strong set striking E. 40° N., and a faint set striking E. 10° N. North-west of Clauchog Farm the striæ run nearly due south, while east of Smuraig the direction is north-east. North of Glenscorrodale the striæ trend 30° E. of N., and north-east of Cnoc a' Chapuill there are many striæ running N.N.E. In the Sliddery Water south-east of Cnoc na Dail, and at the head of the Sliddery Water they strike E.N.E. On the north side of Monamore Glen there are striæ running N.E. and E.N.E., whereas in the burn itself the direction is east and west parallel to the stream course. On the island of Pladda off the south-east coast of Arran the striæ run E.N.E.

Erratics.—Most of the erratic blocks and boulders of Arran are of local origin, a phenomenon no doubt due to the protecting influence of the local ice-cap. Some examples of foreign boulders are given below. G.W.T.

A well-rounded boulder of coarse granite with large crystals of pink felspar is on the shore about half a mile west of the Cock of Arran. It is probably an example of the granite of Glen Fyne which has been carried from the north. About three-quarters of a mile west of Lochranza pier there is, at a height of about 200 feet above the sea and reposing on the schists, a large boulder of brecciated conglomerate very like the kind so common in the Upper Old Red rocks of Bute. Its dimensions are 12 feet long by 9 feet broad, and it is 4 feet high. This block of coarse rock is composed mainly of fragments of quartz and schist. It may have travelled across from Bute. Rock of much the same character occurs also in Arran, but it would not be easy to account for its position here unless it came from outside the island.

The largest of the local erratics are of granite. The heaviest is probably the Clach Mhòr, on the highest raised beach south of the Corrie Burn and about three-quarters of a mile south of the hotel. It is 30 feet square at the base, about 15 feet high, and must weigh about 400 tons. A block still longer than this (36 feet), but probably not so heavy, occurs among the moraines north of Ceum na Caillich. Clach an Fhionn, a split boulder north of Corrie by the roadside, measures 17 feet by 10 by 7, and Clach a' Chait, 600 yards farther north, is 18 feet long, 6 to 9 feet wide, and about 15 feet high. There is a large granite boulder on the Corrygills shore, and large blocks of granite are numerous on the Clauchland shore on the north side of Lamlash Bay, and a few occur high up on the northern slopes of Holy Island. They are abundant on the Old Red Sandstone slope east of Monyquil, where one was measured 17 feet by 8 feet 6 inches; and on the hill-slopes north of Dougrie and on the seashore to the west, where several are as much as 10 feet long. The numerous large boulders of granite and schist that encumber the shore for a distance of a mile and a half north-west from the Iorsa Water have been derived from the denudation of the boulder-clay during the process of cutting back the cliff to form the present raised beach, and the Clauchland shore boulders have probably in like manner been derived from the denuded till of the neighbourhood. W.G.

Boulders of the northern granite are scattered rather generally over the southern part of Arran. Gunn lists some of the more notable occurrences as follows:—Many large granite boulders on north shore of Whiting Bay; in Glen Ashdale region numerous granite boulders, especially south of Glen Ashdale Wood. Other localities are: on hillside south of Largymeanoch 1000 yards east of Cnoc na Comhairle; on the scarp of the Dippin crinanite near Dippin; 300 yards N.N.W. of the keeper's lodge at Kildonan; at a point 500 feet above the sea, between the Allt Mòr and Easa Cumhang, Auchenhew; and large boulder 400 yards north of Drumadoon Farm.

A granite boulder, 4 feet by 3 feet by 3 feet, is perched on the edge of the Cnoc na Garbad scarp near 890 feet O.D.

These occurrences bear testimony to the general southward dispersal of blocks of the northern granite. They were prevented from travelling east or west by the pressure of the ice-sheets which filled Kilbrennan Sound and the Firth of Clyde. Although Arran granite has been recorded from Ayrshire, by Mr. John Smith,[1] on the authority of a local collector, it must be of extreme rarity of occurrence, as many other observers have failed to find it in the drift deposits.[2] G.W.T.

Glacial Deposits.—Till or Boulder-clay.—This well-known irregularly accumulated deposit is often tinged of a red colour and is very unevenly distributed, being mostly confined to the valleys and low-lying ground. Probably the best exposure of it in this area is on the north side of Ballymichael Burn, nearly half a mile above the road, where reddish till or stony clay appears from 40 to 50 feet in thickness. Thick masses of grey till may be seen in the banks of the Cnocan Burn, Brodick, about half a mile above the wood, and compact red till appears in the south bank of Glencloy Burn near Knowe. The general drift of the granite area is less clayey and more loosely aggregated, sometimes much like morainic material in character, though not in form. Thick masses of loosely-constructed brownish drift, with large blocks in it, are exposed in the banks of Allt Gobhlach, Pirnmill, half a mile from the sea, and fine exposures of this loose granitic drift are found by the stream called Allt an t-Siorraim which issues from Loch Tanna. In places on the west side of the stream the drift would appear to be from 50 to 100 feet thick. W.G.

The southern half of Arran is largely smothered under a thick sheet of boulder-clay, which is generally some shade of red in colour, owing to the prevalence of the New Red Sandstone country-rocks in this part of the island. The drift is often somewhat sandy, as, for example, in the region south of Tighvein, and Gunn records beds of red sand in the till east of Port na Feannaiche, near Corriecravie. The thickness of the boulder-clay is especially great in the valleys of the principal streams, as Glen Ashdale, the Kilmory Water, and the Sliddery Water. Thick till caps the cliff at Torr nan Uain, west of Bennan Head, and its denudation has supplied the numerous boulders on the foreshore at that locality.

At several places in the Kilmory and Sliddery Waters a glacial shell-bed is found intercalated in the boulder-clay. Accounts of these beds are given by R. Boog Watson[1] and J. Bryce.[2] The most accessible section is in the Cloined Burn, a tributary of the Kilmory Water, about three-quarters of a mile north-east of Lagg Hotel. Bryce gives the following section at this locality :—

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[1] *Trans. Geol. Soc. Glasgow*, vol. xi., Supplement, 1898, p. 112.

[2] J. W. Gregory, *Trans. Geol. Soc. Glasgow*, vol. xvii., part iii., 1926, p. 364.

7. Surface soil.
6. An upper drift, similar to No. 4.
5. A compact bed of stones, with less sand, forming a marked line on the cliff, but not easily reached. Thickness, 5 or 6 feet.
4. An upper drift of sand and stones ; thickness variable.
3. Dark sandy bed with open texture, 4 or 5 feet, apparently local.
2. Clay bed with shells, 7 to 10 feet.
1. Boulder-clay [very hard and tough], 12 to 20 feet thick.

The shell-bed is seen again on the west bank of the Kilmory Water, opposite Kilmory Church ; and in the Allt na Pairce, near its confluence with the Sliddery Water. The fossils found in these shell-beds are given by R. Boog Watson and J. Bryce as follows :—

Balanus crenatus
Purpura norvegica
Tellina baltica
Cyprina islandica
Astarta elliptica
,, arctica
,, compressa
,, striata
Cryptodon sarsii
Modiola modiolus
Leda pygmæa
,, pernula
Pecten islandicus
,, opercularis
Littorina littorea
Turritella communis
Natica sp.

Many of these shells are in a perfect state of preservation, and indicate quiet deposition on the sea-floor. G.W.T.

Moraines.—Relics of a later and more local glaciation also occur in nearly all the valleys in the shape of moraines. They are especially conspicuous in the valleys at the head of the North Sannox stream on the north side of Caisteal Abhail, and in the upper part of Glen Cloy in both its branches, Glen Dubh, and Glen Ormidale. In the three valleys into which the North Sannox stream divides the moraines are generally an irregular assemblage of small mounds composed of huge blocks of granite, but in addition to this there is a fine example of a lateral combined with a terminal moraine on the eastern and north-eastern sides of the heaps south-east of Creag Dhubh. There is also a linear moraine in the eastern valley—Coire nan Ceum—in addition to the formless heaps. In South Glen Sannox there is a well-formed lateral moraine, more than half a mile in length, which forms a sloping ledge nearly parallel to the stream on the north side of the valley, under Ceum na Caillich. In Coire nan Larach to the north of Am Binnein there is a beautifully-formed lateral moraine strewn with granite blocks, and there is another in Coire Làn at the head of the White Water. A well-marked linear moraine, which is at a low level to the north of Maol Donn, can be easily discerned from the high road south of

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[1] 'On the Great Drift Beds with Shells in the South of Arran,' *Trans. Roy. Soc. Edinburgh*, vol. xxiii., 1864, pp. 523–546.

[2] *Quart. Journ. Geol. Soc.*, vol. xxi., 1865, pp. 204–213 ; *see also* 'Geology of Arran and Other Clyde Islands,' 4th edition, 1872, pp. 44–48, 180–192.

Corrie. It has a north-east trend. Moraines are common in the Iorsa valley, and there are fine examples near the head of the Garbh Choire Dubh west of Cir Mhòr. In Glen Rosa they are found less than half a mile west of the wood and below the upper limit of the 100-ft. beach, and they are prominent again two miles farther up the valley where it divides into three. The upper part of the Garbh Allt branch glen, for a distance of a mile from the head of the valley, is almost one sea of moraines. In Glen Dubh (Glen Cloy) there is a magnificent series arranged for the most part in concentric curves round an alluvial flat at the foot of the crags which must at one time have been a glacial lochan, or a tarn, dammed by moraines.

In the valley of the Machrie Water, about Monyquil and Glaister, and also up the Machrie Burn, mounds of detritus occur which at a distance might be mistaken for moraines, but which when closely examined are found to consist of washed sand and gravel. They are, therefore, more of the nature of eskers or kames. On the Machrie Burn they are conspicuous to the west of Cnoc na Ceille, where they form an irregular group stretching for a quarter of a mile parallel to the burn on its east side. On the west side, a line of them, almost a continuous ridge, may be traced to the north-westward for nearly half a mile. On the Machrie Water the best examples of them are found between Monyquil and Machrie Bridge on the west side of the river, and mounds of much the same character are found near the road which runs past Derenenach and Ballymichael to Shiskine. East of Ballymichael these mounds are very striking, and pits have been opened in them in several places for gravel and sand. Pits have also been made in the long mound between Machrie Bridge and Glaister. One of these mounds of a curved shape, south-west of Monyquil, is known as 'The Serpent Mound,' and is supposed to be artificial. W.G.

According to Prof. J. W. Gregory,[1] the banks of sand and gravel east of the main road north of Shedog are surface washes of sand and gravel down the steep slope of boulder-clay on which they rest. The 'Serpent Mound' south-west of Monyquil, is a bank of denuded morainic material, a remnant of a terminal moraine. The mounds in the Machrie Burn are regarded by the same authority as clayey moraines. Prof. Gregory also describes a line of mounds at Driminigar, east of Blackwaterfoot, which are the remnants of a curved moraine. A small hillock of sand and gravel occurs at the end of the long mound, and is due to a fan formed by a stream that had cut through the moraine. G.W.T.

POST-GLACIAL AND RECENT

Raised Beaches.—The 25-ft. raised beach is a marked feature on the coast-line of Arran. Though often very narrow it is very persistent. It may disappear for a time at a rocky promontory but shortly reappears. Sometimes it is but a shelf cut in the rocky shore with no deposit of gravel on it, and occasionally, as in the case of the Scriden and the Fallen Rocks in Arran, the original shelf has been obliterated by a comparatively recent landslip. The marine shells found in the sand and gravel of this lower raised beach or lying loose on its surface, appear all to be of species now living in adjoining seas, and are a testimony to the recent elevation of the land. A list of some found in a field about a mile south of Corrie is given by Sir A. C. Ramsay.[1] A separate beach at the height of the '40 feet' seldom occurs, except at the mouths of the large streams or in sheltered bays. In fact, both the 25-ft. and 40-ft. beaches are represented by the continuous marine terrace above described, which is often bounded by high sea-cliffs in which water-worn caves occur at various levels. These latter are conspicuous between Brodick and Corrie on the eastern side of Arran in the New Red Sandstone; and several are found hollowed out of the schist on the north-west coast. A remarkable group is associated with the King's Cave near An Cumhann on the Tormore shore.

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[1] 'The Scottish Kames, and Their Evidence on the Glaciation of Scotland,' *Trans. Roy. Soc. Edinburgh*, vol. liv., part ii., 1926, pp. 404–405.

The higher and older marine terraces have evidently suffered much denudation by the action of the sea along the exposed part of the coast, and by streams at their mouths, and in the bays of Brodick and Lamlash, where several burns enter the sea. In these latter situations the marine and freshwater alluvia are mingled so that it is difficult to class them separately. We have evidence, however, of several beaches at different levels rising from 40 or 50 feet to over 100 feet above the sea, which are beautifully exhibited near the mouths of the Iorsa and Machrie streams in Arran. At the time of greatest depression the sea penetrated far up into many of the valleys; Glen Rosa and Glen Cloy were sea lochs, each 1½ miles in length; Loch Ranza was lengthened by one mile, and Lamlash Bay extended one mile farther to the west. North Glen Sannox was a long narrow sea loch, and at Catacol and South Sannox there were broad, short lochs. Perhaps the greatest changes in Arran would be on the western coast, where not only was there a sea loch at the mouth of the Iorsa but in the plain of Shiskine the sea penetrated in an irregular way to more than 2 miles eastward of its present boundary, and the hilly ground of Torr Righ Beag and Torr Righ Mòr formed a separate island. Good sections of the gravel and sand of the higher beaches are exposed in the north bank of the Rosa Burn one mile from the sea, the south bank of Sannox stream opposite Mid-Sannox House, the east side of the Iorsa Water above Dougrie Lodge, and in a gravel pit at Lochranza above the junction of the two main streams and west of Ballarrie.

Freshwater Alluvia.—As might be expected from the small size of the streams the patches of freshwater alluvium are generally small and unimportant. The largest are found in the plain of Shiskine, on the Machrie Water above the old bridge, and stretching south-westward along the valley of the Black Water to Drumadoon Bay; in the Iorsa valley above Iorsa Loch, and at the mouths of the Iorsa, Catacol Burn, Easan Biorach, the two Sannox Burns, those which enter the bays of Brodick and Lamlash, Glen Ashdale,

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[1] 'Geology of the Island of Arran from Original Survey,' 1841, p. 19.

Kilmory Water, and Sliddery Water. The alluvium at the debouchure of the streams has been to a great extent formed from the denudation and rearrangement of the material forming the raised beaches. In the Shiskine district the alluvium of the swift-running streams on the east side has been spread out in fan-like or delta forms over the marine material. The alluvial sand and gravel of the Machrie is 2 miles in length and nearly half a mile broad in places, and has been accumulated by several swift-running streams of considerable size. At first sight it might be supposed that the material has filled up an old loch, but the fact that there is a rise of quite 100 feet between the foot and the upper end rather militates against this view. The patch of alluvium in Glen Iorsa is nearly as broad as the last and is 3 miles long, and here there must have been at one time an extensive sheet of fresh water which, including the present Loch Iorsa, may have been 3½ miles in length. For a distance of more than a mile above the last-named loch the alluvial flat is studded with small lochans, and the rise in level is but 7 or 8 feet. Even at a distance of more than 2 miles above Loch Iorsa the alluvial flat is only 30 feet higher than the loch. A beautiful example of a filled-up lochan, an old moraine-dammed tarn, occurs at the head of Glen Dubh at the foot of the steep crags. The present extent of the alluvial flat shows this lochan was about 400 yards long and 300 broad. Old lochans or tarns which have been filled up are now generally peat-bogs. It is evident that several of the streams have changed their courses in the low-lying ground near the sea. In an old manuscript map of the latter part of the eighteenth century the Rosa Burn is represented as taking a sweep round to the eastward in what is now the deer-park, and the Cnocan Burn came southward towards it. The marked bank in the park south-west of the cottages shows where the old stream ran. At that time there was a project to make an artificial channel connecting the Rosa Burn with the mouth of the Cnocan in order to form a harbour opposite the castle. The lower part of the Cnocan Burn is now an artificial cut. There is still trace of a large bend, an old course of the Rosa, west of Strabane. The mouth of this stream has undergone several changes. At one time it ran along the sands towards the Cnocan, and afterwards changed to a straight course out to sea. Then it turned to the north again and its outlet, when the Ordnance Survey was made, must have been nearly 700 yards north of what it is now. The present run straight out to sea is, however, said to be owing to an artificial cut having been made. It has been in existence many years, but is not on the revised ordnance map. The greater part of the water of Ballymichael Burn is now carried by an artificial channel into the Machrie Water, to the east of the Stone Circles of Tormore.

Peat.[1]—The high ground on which peat accumulates is mostly in the southern half of the island. It covers most of the Central Ring Complex from Beinn Bhreac to A' Chruach, and is thick over the greater part of the region south of Tighvein, and in the valleys of the Sliddery and Kilmory Waters. The higher granite hills are almost bare of vegetation, but there is a good deal of peat, however, on the lower granite area from Glen Catacol eastward to An Tunna, and it is abundant on the high plateau-like or gently-sloping ground formed of schists, nearly all round the granite district. It is found, in fact, over the rocks of all formations in Arran, from the oldest to the boulder-clay of the Glacial period.

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[1] *See also* p. 269.

Blown Sand.—Blown sand is not common around the coasts of Arran. The most extensive areas are on the west side of the island, at Machrie Bay, and on either side of the Black Water at Blackwaterfoot, where it forms typical seaside links—mounds of loose and shifting sand interspersed with rolling grassy hollows. The only other place where blown sand occurs is on the shore at Eilean Mairi, three-quarters of a mile south-east of Lagg Hotel.

Landslips.—Probably the largest area covered by a landslip in Arran is that which is found in the hollow north of Maol Donn, between it and An Sgriob. Large masses both of Carboniferous and Permian rocks are scattered over an area which is 600 yards in length from south-west to north-east, and on an average more than 200 yards in breadth. The extent of this slip must be quite 25 acres. Other notable landslips, which have often been described, are those which form the Fallen Rocks and the Scriden. The former make a striking debacle of large blocks, from a height of 500 or 600 feet down to the sea-level between North Glen Sannox and Millstone Point. The slipped masses are all of Upper Old Red conglomerate. The Scriden covers a larger area at the most northerly part of the island. It is formed of large blocks of New Red sandstone and conglomerate which fell, it is said, some two hundred years ago. The concussion shook the earth, and the fall was heard in Argyllshire and Bute. In addition to the masses which have actually fallen, several parts of the hill above have moved slightly from their position and left deep and narrow rents, one of which is known as the Fairy Dell.

In the south of Arran, while there is a considerable rock fall at Dippin, most of the landslips represent slides of boulder-clay over solid rock. There are notable examples of this type of landslip on the north side of Clauchan Glen, in Monamore Glen, Glen Ashdale, and near High Clauchog. W.G.

CHAPTER XVIII

ECONOMIC GEOLOGY

ARRAN has little to show in the way of materials of economic value. The only mineral deposit now being worked on a commercial scale is the barytes of Glen Sannox.

Coal.—The coal formerly worked on the shore at the Cock Farm in Arran is referred to by most of the older writers on the island. All agree that the seam or seams belonged to the type of blind or glance coal. It was difficult to work, and principally used for the purpose of making salt from the sea water. The old salt pans are close to the old workings. It was probably also used for burning the limestone near Laggan. Two or three seams are said to have been worked, the principal seam being 3 or 4 feet thick ; but though more than one seam may have been found it seems probable that the workings were almost entirely confined to the thickest seam. They are very old and were discontinued considerably more than 100 years ago, probably before 1773, as under that date in the estate accounts there is a record of boring at Cock for coal. In the same year a boring for coal was made on the north side of Lamlash Bay on the Clauchland shore to a depth of 114 feet 5 inches, which naturally proved unsuccessful.

It is remarkable that no coal is found at Corrie or elsewhere in the island in the strata corresponding to those at the Cock in which coal has been worked ; and while strata of Coal Measures age are now known to occur at five different localities in Arran in addition to that of Sliddery Water Head, in none of them do coal-seams occur. An interesting question therefore arises as to the possibility of finding workable coal seams beneath the New Red Sandstone rocks. It is not likely that such seams occur on the north end of the island at the Cock, because the unconformity between the two formations is there apparently very slight, and the area in which they could possibly be found is so small that it would be scarcely worth while to determine the matter by boring. Nor would it be advisable to try the western side of the island, because there the New Red Sandstone overlaps the Carboniferous formation entirely, and reposes on the Old Red Sandstone. If the matter were to be tested, it would be best, therefore, to choose the eastern side of the island, and to select a spot several miles distant from the area at Sliddery Water Head. There is a possibility of meeting with some of the higher Coal Measures in a district where they have been faulted down prior to the deposition of the New Red rocks.

Even if the Coal Measures were thus found by boring, however, the coals themselves might be absent, or poor in quality, or burnt and rendered useless by the igneous intrusions so numerous in the island. The edge coals which have been worked at the Cock are not met with in the corresponding strata at Corrie, although their positions are marked by *coal seats*. Neither has any trace of coal been detected among the rocks exposed at Sliddery Water Head, although in the equivalent beds at Kilmarnock coal seams are abundant.

Peat.—There are extensive tracts covered with thick peat in the island of Arran, mainly on the higher plateau-like ground between 700 and 1700 feet above the sea, but occasionally it is found at lower levels, as on the old raised beaches on either side the lower part of the Machrie Water. It was formerly much used for fuel all over the island, and almost everywhere old peat roads to the hills still exist, though they are not marked on the ordnance maps. On the east side peat for fuel has almost entirely been replaced by coal, but on the west side a little peat is still cut and used in the Shiskine district and northwards to Imachar and Lochranza.

Towards the south peat is still cut on Beinn Tarsuinn, near Torr an Daimh, Cnoc Clauchog, Innis Dubh, south of Smuraig, and east of Cnoc na Garbad, to supply the remoter farms of the interior and the south coast. West of Cnoc Clauchog the peat is of great thickness, no less than six or seven cuts in depth having been got out. The coal strike of 1926 led to the reopening of peat diggings all over the island.

Ironstone, Bog Iron-Ore, and Old Iron Workings.—To the north of the landing-place at Corrie is a thin band of clay-ironstone which crops out also to the westward on the hillside, where it is from four to six inches in thickness. It appears to be of good quality, and we were informed that some hundreds of tons of it were formerly exported. Probably it was not mined for, but was collected during the working of the white freestone quarries. A similar band occurs in the section on the Cock shore. A number of old bloomeries exist in the island which have been described by W. Ivison Macadam.[1] Three of these are on the farm of Glenkiln near Lamlash, and in one case there is evidence that bog iron-ore was used. Two sites occur in Glen Cloy to the south-west of Glenrickard, and there were two near the road leading from Brodick to Lamlash, in one of which the slag was utilized for road-making. Another was at Coillemore near Lochranza. At Kilpatrick, Shiskine, W. Ivison Macadam states that the slag exists in considerable quantity, and is of the dense black variety characteristic of the oldest period. On the top of a ridge or mound there is a rude stone building with a circular hollow about 9 or 10 feet in diameter, and the slag has been thrown down the slope. Another site is near Largybeg, on the upper side of the road, where about ten cart-loads of slag were used for drains. On the farm of Gortonallister, south of Lamlash, scattered slag occurs at a point on the western side of the road on the banks of a small stream almost at the summit of the road. In all these cases charcoal appears to have been the fuel used for smelting, and the slag remaining is of the dense black type characteristic of the early period when the smelting process was very imperfect, and a large percentage of iron still remains in the slag.

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[1] 'Notes on the Ancient Iron Industry of Scotland,' *Proc. Antiq. Soc. Scotland*, vol. xxi., 1886, pp. 89–132.

Barytes.—A well-known barytes mine is at present being worked in Glen Sannox. The following account is taken mainly from the Geological Survey Memoir on Barytes and Witherite.[1] I am indebted to Mr. Robert Robertson, principal of Messrs. Martin, Barrowman & Co., the lessees of the Glen Sannox mine from the proprietor, the Duke of Montrose, and to Mr. Bryce Longmuir, the manager, for further information freely accorded.

The mine is situated about half a mile up the Glen Sannox Burn, access to it being obtained by a new track which leaves the main road about 100 yards south of the bridge over the Sannox Burn. The occurrence of barytes at this locality has been recognized for over 130 years, and the vein was known to T. Pennant,[2] R. Jameson,[3] J. Headrick,[4] J. Macculloch,[5] and others. When Ramsay[6] visited Arran about 1840 the mine was being worked, and dressing and washing plant had then recently been erected. He describes the process for the manufacture of the finished barytes, which seems to have been almost identical with the method now followed at Muirshiels (Renfrewshire). He also describes a method whereby the barytes was stained yellow by means of chromate of lead.

From 1840 to 1862 the mine appears to have been in continuous operation, but soon afterwards it was closed and the mill dismantled. The output of barytes from 1853 to 1862 was as follows :—

Year.	Tons.	Cwts.	Year.	Tons.
1853	600	19	1858	550
1854	550	—	1859	—
1855	550	—	1860	550
1856	550	—	1861	625
1857	—	—	1862	730

In 1918 the mine was reopened, but little work was done. In 1920, however, about 300 tons of excellent barytes were raised and exported from the island. A new shaft was then sunk ; and a railed incline with a self-acting conveyor, and a new loading pier, have now been added to the equipment. About 10,000 tons of barytes have now been raised, the greater proportion of which is on the dump. The export of this material is awaiting the completion of a new barytes mill in Glasgow. Only water power is used in the working of the mine. As regards quality the Sannox barytes is regarded by good authorities as the best in the country. The product is a ' blue ' barytes, which, when milled, yields an intense white material superior to the best German mineral. So far as present information goes the reserves are very large.

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[1] Special Reports on the Mineral Resources of Great Britain, vol. ii., ' Barytes and Witherite,' 3rd edition, 1922, pp. 100–101.

[2] ' A Tour in Scotland and Voyage to the Hebrides,' 1774.

[3] ' Mineralogy of the Scottish Isles,' 1800.

[4] ' View of the Mineralogy, etc., of the Island of Arran,' 1807.

[5] ' Western Isles,' 1819.

[6] ' The Geology of the Island of Arran from Original Survey,' 1841, pp. 23–24.

The country-rock consists of interbedded sandstones, conglomerates, and mudstones of Lower Old Red Sandstone age. Near the old mine the main vein where it crosses the Sannox Burn has been excavated by the old miners. It trends almost due north and south, and dips westward at a high angle; heavy stringers in the hanging wall, although of good quality, were left in place. About 50 yards farther down the north side of the burn, another vein can be seen, which is about 2 feet wide and trends north-west. On the hillside to the north and north-west of the mine, no less than four veins have recently been discovered. They all trend about north-west, and carry from 2 to 5 feet of barytes. In all probability one of these is the continuation of the main vein. The mineral has now been traced over the divide into North Glen Sannox.

The exact width of the vein where it crosses the burn has not been ascertained, but the sole of the level, driven only a short distance below, shows from 8 to 9 feet of good barytes. Still deeper exploration has recently shown that the vein widens out to 26 feet, and still tends to widen downwards.

Two shafts have been sunk, one on either side of the burn, which communicate with one another by a level driven under the burn at a depth of about 100 feet. From the southern shaft the level has been continued 60 yards farther to the south. At the northern shaft the main vein is seen to be cut by another vein which trends north-west; the level has been driven along this other vein. At and near the junction of the two veins, there were several false walls, and the barytes swelled out into a pocket over 12 feet in width.

The barytes thus seems to occur in a system of fissures and fractures trending between north and north-west, and has filled the lenticular cavities produced by the differential movement of the irregular walls of the fissures.

Building Stone.—There are extensive old quarries in the white Carboniferous freestone of Corrie which was much wrought a century or more ago. It was used in the construction of the Crinan Canal, and is said to have been shipped to the Isle of Man for building purposes. At present the red freestone at the base of the New Red Sandstone is the principal building stone in Arran, and there are large quarries in it at Brodick and Corrie. The stone is soft and easily worked, and is said to harden by exposure to the air. Large blocks of it can be obtained, and from Corrie the stone was largely exported to various parts of the Clyde district, and some going much farther away—a mansion in Rum being built of it. Troon harbour is said to have been built out of the material from the northern quarry. In the neighbourhood of Lochranza a tough, gritty schist is used for building purposes.

In the southern part of the island red sandstones belonging to the Lamlash–Machrie group furnish good building stone, and large quarries exist at Cordon and Monamore Mill, as well as smaller ones elsewhere. The present condition of these quarries shows that very little stone has been taken from them of recent years. The thick acid and basic sills are also utilized for the same purpose, a quartz-porphyry near Glenrie Mill affording a good building stone. Formerly the rock of Brown Head (quartz-porphyry) was worked in this way, as was noticed by Ramsay, who says: 'The blocks on the shore (Leac a' Bhreac) have been quarried for economical purposes.'[1] There are distinct signs of quarrying on the cliff near the Preaching Cave on the shore at Kilpatrick.

Slate.—Rough slates of a grey colour were formerly worked at the quarries south of the Cock Farm in Arran. In the Brodick estate office there are records of these last workings, from which we learn that between 1773 and 1776 between two hundred and three hundred thousand were sold at prices of £1 per thousand and upward. Work was also carried on here between 1776 and 1781. Most of the slates from this locality have disappeared from the house-roofs of the neighbourhood, but some still remain in Lochranza and North Newton.

Limestone.—There are extensive old limestone quarries at An Sgriob, to the north of Maol Donn, and at Corrie. The latter are much the largest; they extend up the steep hillside for a quarter of a mile, and the limestone has been much wrought in artificial caves, besides having been worked at the outcrop towards the dip till in places there was nearly 30 feet of cover.

During the Great War a very pure limestone containing 99 per cent. of $CaCO_3$ was quarried on the North Locherim Burn, at a point a third of a mile north-north-west of High Corrie. A tram line was laid down to convey the material to the stone quay south of Corrie.

The pebbly limestone of the Clauchan Glen was long ago extensively burnt for lime, and roads, now erased from the map, were made to the quarries from Shiskine and Burican. There are old limekilns at Clauchog, and white Irish limestone (chalk) was at one time imported and burnt in these kilns, as well as at Shiskine.

Road Metal.—The numerous igneous intrusions, especially the basic dykes and sills, afford abundance of excellent material for road-making almost everywhere. The acid rocks are not so much used for this purpose. However, a felsite sill is so used near the Brodick and Lamlash road, as also the granite near Derenenach on the Shiskine side of Arran, and the diorite from the quarry at the bridge over the Allt nan Calaman on the String Road. The hard sandstones of the Lower Old Red formation are used for road material in one or two places, as on the String Road in Glen Shurig, and the gravel from a raised beach near Ballarrie, Lochranza, is taken for a like purpose.

Notwithstanding the abundance of excellent local road-metal, there has been a considerable import in recent years of road-metal from the Loch Fyne quarries, it being probably cheaper to carry stone from these well-established and well-equipped quarries than to extend and equip the small quarries on the island.

Ganister, Fireclay, Moulding Sand.—The exigencies of steel manufacture during the Great War stimulated the search for ganister and moulding sand in Arran. A 'ganister' about 1 foot 9 inches to

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[1] 'The Geology of the Island of Arran from Original Survey,' 1841, p. 54.

2 feet in thickness is exposed on the foreshore near the drain in front of Corrie Hotel. It is a fine-grained, white, hard, compact sandstone, with numerous rootlets. Its exact geological horizon is difficult to determine owing to faulting, but it is probably somewhere near the top of the Upper Limestone group of the Carboniferous Limestone Series. Rocks of this age are exposed at several localities on the hill slopes between Corrie and Brodick Castle, and there should be a fairly extensive field of this ganister. There are good harbour facilities at Corrie.[1]

The bauxitic fireclay horizon of the Millstone Grit has been found in Arran, where it appears to be an extension of the North Ayrshire field.[2] It is best seen on the sides of the Merkland Burn, north of Brodick Castle, about half a mile up the stream from the Brodick–Corrie road. The section shows 5 to 6 feet of pale pink, hard, fireclay with occasional red irony patches, resting directly on a highly-decomposed, ferruginous lava-flow. Although this clay is very similar in many respects to ordinary bauxitic clay, it is not truly bauxitic, since it contains an excess of silica. Its refractory quality is therefore not so high as that of the clay found in North Ayrshire.[3]

Two analyses of the fireclay from the Merkland Burn are given below :—[4]

SiO_2	51·90	49·72
TiO_2	4·06	3·32
Al_2O_3	32·96	34·80
Fe_2O_3	3·48	4·08
Combined Water	7·44	7·37

Red sandstones, regarded by Prof. P. G. H. Boswell as suitable for the purpose of providing good moulding sand of the same character as the Belfast or Mansfield sands, occur in the south of Arran, and belong mainly to the upper part of the Lamlash–Machrie group of the New Red Sandstones.[5] From the point of view of transport the best site for working them would appear to be the old quarry in the raised-beach cliff about one mile south of Whiting Bay Pier. There is a small jetty a quarter of a mile north of this quarry, and a good road connects them. The soft, well-bonded red sandstones occur as beds sometimes 20 feet thick, interbedded with more massive, calcareous, yellow sandstone of Glen Dubh type.

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[1] Special Reports on the Mineral Resources of Great Britain, vol. vi., 'Refractory Materials: Ganister, Silica-rock, Sand, Dolomite: Resources and Geology,' *Mem. Geol. Surv.*, 2nd edition, 1920, p. 156.

[2] Special Reports on the Mineral Resources of Great Britain, vol. xiv., 'Refractory Materials: Fireclays: Resources and Geology,' *Mem. Geol. Surv.*, 1920, pp. 230, 235.

[3] G. V. Wilson, 'The Ayrshire Bauxitic Clay,' *Mem. Geol. Surv.*, 1922, pp. 5, 8, 24.

[4] Special Reports on the Mineral Resources of Great Britain, vol. xxviii., 'Refractory Materials: Fireclays: Analyses and Physical Tests,' By F. R. Ennos and A. Scott, 1924, pp. 47, 64.

[5] 'A Memoir on British Resources of Refractory Sands for Furnace and Foundry Purposes,' Part i. London, 1918, p. 169.

Sandstones which could be easily crushed to serve either for glass-making or as hearth-sand for furnaces have been noted by Mr. G. V. Wilson in the Carboniferous rocks of the Corrie shore.[1] Several excellent examples were noted, particularly at the bathing pool near Corrie Post Office, and at an old quarry on the hillside just behind the Corrie Hotel. In the main these rocks are reddish; but some are white, even-grained rocks forming beds up to 20 or 30 feet in thickness. The reserves are large, and there are good harbour facilities.

Soil and Agriculture.—The alluvial flats and raised beaches at the mouths of the principal streams afford the best soil, and the narrow terrace or raised beach round the island is in general carefully cultivated. The upper limit of enclosed and cultivated land is between 400 and 500 feet above the sea, but the greater portion is below 300 feet. As in the northern part of the island the ground rises steeply from the sea, almost everywhere the arable land is necessarily but a narrow belt along the coast, and even there is not continuous, though apparently more land was formerly cultivated in the olden times. In the Millstone Point district there were at one time fourteen families residing at Cock, Cuithe, Laggan, and Laggantuin, where there are now but a farmer and a shepherd. In North Glen Sannox there was once a large population where is now but a solitary shepherd's house. Several deserted farmsteads in the high fields above Corrie, at North High Corrie, and elsewhere, tell of former cultivation where all is now pasture land.

The southern part of the island probably contains considerably more than one half of the total arable land. Along the coast, in the Black Water valley, and near Lamlash, the strips of cultivated ground have a light, gravelly soil, peculiarly suitable for the growth of potatoes. Arran growers, notably Mr. D. McKelvie of Lamlash, have specialized in the cultivation of seed potatoes, of which they have established many new varieties held in high repute. In the south end, however, which is the most valuable of the agricultural districts, the subsoil is stronger and of a more clayey nature than in any other quarter of the island, no doubt owing to the wide spreads of boulder-clay. The amount of land under the plough has probably not varied much for the last hundred years. In a few places additional land has been reclaimed from the moors, while in others old arable land has relapsed into the general pasture, as at Corriehaim and Gargadale in the Sliddery valley.

There is evidence that it was at one time the general custom in the island to take the cattle to mountain pastures in the summertime, and remains of the summer shielings or *airidhs*, as they were called, are common in nearly all the high glens.

The old runrig system of cultivation, which was general a hundred years ago, still exists at Balliekine.

There is much natural wood in Arran, mostly of birch, alder, hazel, rowan, and willow, with some scrubby oak. Belts of these trees are found along the sea coast from Dougrie to Lochranza on the west coast, and on the east coast between Sannox and Brodick. There is a good deal of natural wood also in the lower parts of some of the glens, especially in Lag a' Bheith and in Glen Cloy, also in the Shiskine district near the Machrie Water, and in the lower part of Glen Rosa. In Glen Dubh (Glen Cloy) the wood grows up to about 800 feet above the sea, and to nearly the same height in Coire Fhraoich (Glen Rosa), and on the higher ground west of Corrie. Along several of the smaller streams trees flourish up to nearly 1000 feet, especially if the streams run in ravines, but the only locality where there is a small forest at this height is at Doire na Ceardaich, to the east of the summit of the Corrie and Lochranza road. One or two stunted specimens of the rowan tree were observed on the north side of Glen Sannox at a height of about 1500 feet near Suidhe Fhearghas.

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[1] Special Reports on the Mineral Resources of Great Britain, vol. vi., 'Refractory Materials: Ganister and Silica Rock-Sand, Dolomite: Resources and Geology,' *Mem. Geol. Surv.*, 2nd edition, 1920, p. 196.

The southern half of the island cannot be said to be well wooded, as the western and southern coasts are comparatively bare. There is a good deal of natural wood in places on the east coast, especially about the crags at Dippin and Kingscross, and along the coast west of the latter point. Much of it, as elsewhere, consists of birch and hazel. Most of the small streams flowing into Whiting Bay have pretty strips of natural wood along their banks, and there is a good deal in the lower part of the Monamore Glen. Between this glen and the Kingscross Burn lies Lagavellie, around which is one of the best wooded districts in this part of the island. Elsewhere what wood there is generally grows along the banks of the streams, and Sliddery Water and portions of its tributaries are bordered with trees in many places, the alder being conspicuous. The Kilmory Water in part is also fairly wooded. The Black Water and the smaller streams which debouch into Drumadoon Bay, have likewise their strips of greenery.

In North Arran the largest fir plantations are around Brodick Bay; and up the Merkland Burn and in Glen Shurig these trees flourish up to nearly 700 feet above the sea. There are plantations also at Whitefarland, Sannox, South Corrygills, etc. Glen Iorsa in Arran is almost treeless, and the granite district generally is comparatively bare of wood.

Comparatively little has been done in the southern part of Arran to remedy the deficiency of natural wood. Only a few plantations exist, and none are large. The most important are in Glen Ashdale; along the small burns west of Kildonan; and along the banks of the Kilmory Water at Lagg.

Water Supply.—The rainfall in this west country is heavy, some 40 inches per year and upward; and the water supply from springs and streams is almost everywhere abundant. The water from the northern granite area is beautifully fresh and clear, and several of the springs which supply the streams are very powerful. One of these, three-quarters of a mile from the shore at Corrie, rises near the edge of the granite and furnishes the greater part of the water of the Locherim Burn. Another strong spring is found near the head of North Sannox at the foot of Garbh Choire, south-east of Creag

Dubh. It rises at the edge of a moraine, and strong springs rise in a like position in the corrie west of Cir Mhòr. One of the most remarkable of the springs is that which rises on the ridge south of Caisteal Abhail at a height of nearly 2400 feet. The hillside west of Caisteal Abhail is called from it Leac an Tobair, or the Slope of the Well. One famous well at Mid Thundergay on the west side of Arran, Tobar Challumchille, takes its name from St. Columba. Several shallow wells have been sunk for water in the gravel and sand of the raised beach at Tormore. Another at the most southerly house by the roadside is about 14 feet deep. The greater part of it is in rubble and clay (glacial drift), but the lower part is sunk 2½ feet in yellowish sandstone like that seen at the King's Cave.

In the southern part of the island the supply of water, mostly from small streams and springs, is good and copious.

Population.—The distribution of the people has little connection with the geological formations, the population being confined in Arran to the neighbourhood of the coast and to the lower parts of some of the glens. The district of Shiskine, on the west side, is the only exception, and here a few scattered farms are found some distance from the sea. The resident population of Arran is small, but is much increased in the summer months by an influx of visitors, so that the inhabitants are probably doubled in number. Many of the natives find employment in the summer in catering for the visitors in various ways, but the majority of the people are engaged in agriculture, and the cultivated parts of the island are practically those in which the people reside. The remainder, and by far the larger portion, is devoted to sheep and deer.

The fishing industry is almost extinct, and chiefly confined to that of herrings on the west coast off Lochranza and Pirnmill.

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